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Design Calculation or Analysis Cover Sheet

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Attachments	Total Number of Pages
Attachment 1 – Pool Water Treatment and Cooling System Piping Layout	3
Attachment 2 – Gilbert Boissy E-mail Regarding Spent Fuel Pool Turnover Rate	1
Attachment 3 – Spent Resin Handling System Piping Layout	2

RECORD OF REVISIONS

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DISCLAIMER

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FIGURES

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TABLES

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ACRONYMS

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BWR	boiling water reactor
DPC	dual-purpose canister
HVAC	Heating, Ventilation, and Air-Conditioning
LWT	legal-weight truck (cask)
$NPSH_A$	net positive suction head available
PDC	*Project Design Criteria Document*
PWR	pressurized water reactor
SNF	spent nuclear fuel
STC	shielded transfer cask
TAD	transportation, aging, and disposal
TDH	total dynamic head
WHF	Wet Handling Facility

1. PURPOSE

The purpose of this calculation is to size the pool water treatment and cooling system for the Wet Handling Facility (WHF) pool. This includes identification of major components of the system, the requirements of the system, equipment selection and sizing, and sizing of major process piping. This calculation provides input for the development of piping and instrumentation diagrams, the design of the deionized water system, spent resin handling system, the pool level monitoring instrumentation, and the solid model of the WHF. The WHF pool encompasses the dual-purpose canister (DPC) staging area and the fuel transfer and fuel staging area.

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2.3 DESIGN CONSTRAINTS

None

2.4 DESIGN OUTPUTS

2.4.1 *Wet Handling Facility Pool Water Treatment and Cooling System Piping & Instrument. Diagram*. 050-M60-PW00-00101-000

2.4.2 *Wet Handling Facility Pool Water Treatment System Train A Piping & Instrument. Diagram*. 050-M60-PW00-00102-000

2.4.3 *Wet Handling Facility Pool Water Treatment System Train B Piping & Instrument. Diagram*. 050-M60-PW00-00103-000

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2.4.5 *Wet Handling Facility Pool Water Cooling System Piping & Instrument. Diagram*. 050-M60-PW00-00105-000

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3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

3.1.1 Operational Turnover Rate

Assume that the fuel transfer and fuel staging area of the WHF pool will have a turnover rate of 24 hr for filtration to maintain clarity of the pool water.

Rationale–This is an operational assumption based on expected fuel transfer operations in the WHF pool. A turnover rate of 24 hr is needed to maintain sufficient clarity in the area where the fuel is transferred as stated in Attachment 2 (Reference 2.2.31). This assumption will be confirmed as operational methodology is developed.

3.1.2 Wet Handling Facility Pool Dimensions

The assumed plan dimensions of the WHF pool are shown in Figure 1. The DPC unloading bay, fuel staging area, and fuel transfer area are each 52 ft deep with 4 ft of freeboard so the water is 48 ft deep. The shelf is raised 18 ft from the bottom of the pool. The DPC unloading bay wall rises above the pool water surface. The wall between the fuel staging area and the fuel transfer area rises 20 ft from the bottom of the pool.

Rationale–The dimensions of the pool are based on the WHF general arrangement drawings (References 2.2.2 to 2.2.4 and Reference 2.2.6). The thickness of the walls separating the areas of the pool is based on information from the Structural Analysis group. The actual dimensions will be established after completion of the structural analysis for the pool. These dimensions are used to calculate the WHF pool volume. The freeboard for the WHF pool is consistent with *Wet Handling Facility Layout Study* (Reference 2.2.8, Section 2.3.2).

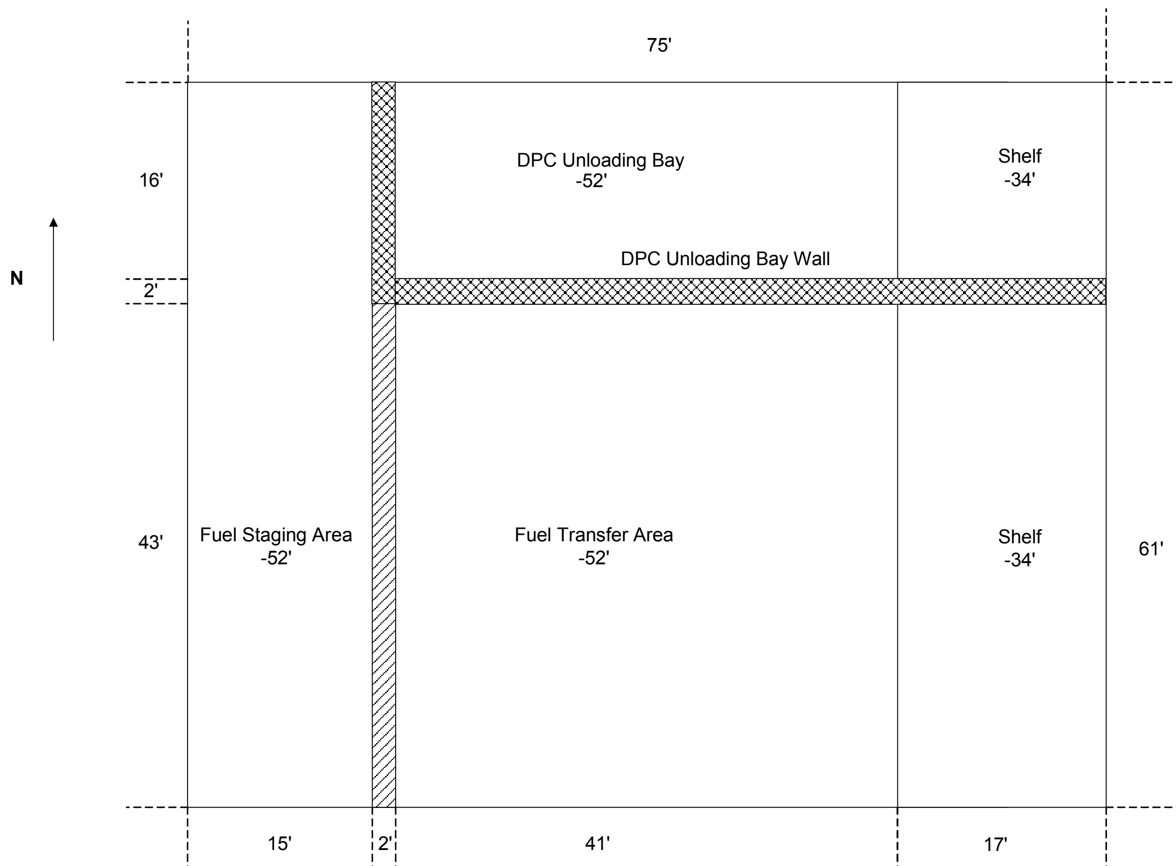


Figure 1. Wet Handling Facility Pool Layout

3.1.3 Centrifugal Pump Efficiency

The efficiency for a centrifugal pump is assumed to be 60%.

Rationale–Efficiencies for centrifugal pumps during normal operation are in the range of 60% to 80% (Reference 2.2.37, Section 13.6, p. 379). To allow for the worst case scenario, an efficiency of 60% is used.

3.1.4 Leak Detection Sumps

The two leak detection sumps are assumed to be located 56 ft below ground floor elevation.

Rationale–The two leak detection sumps are shown in rooms B001 and B009 of WHF general arrangement ground floor and pool plans (References 2.2.2 and 2.2.3). However, the depth and dimensions of the leak detection sumps are not shown on the general arrangement drawings for WHF (References 2.2.3and 2.2.4). The sumps must be located below the bottom of the WHF pool (−52 ft). A 4 ft difference in height allows for sloping and installing the pool liner piping.

3.1.5 Estimates of Piping Lengths

Attachment 1 presents the assumed piping layout for the cooling water piping system, including pipe lengths shown in Table 1. The cooling water supply and return to and from the heat exchangers are assumed to be identical because they follow the same routing. The cooling water piping is a closed-loop system.

Table 1. Estimated Piping Lengths for Cooling Water

Node	Length (ft)	Direction	Elevation (ft)
Cooling Water Supply to the Heat Exchanger			
Node 40 (Outlet to Chiller Pump)	25	Up	0
	12	North	25
	30	East	
	34	North	
	34	East	
	19	South	25
Node (39) Inlet Heat Exchanger			
Total	154	(Use 160)	25

Attachment 1 also presents the assumed piping layout for the pool water treatment and cooling water piping system, including pipe lengths shown in Table 2. The discharge piping from one of the pool water treatment pumps is divided into three parts: through the treatment train, through the heat exchanger, and from the heat exchanger to the discharge header back to the pool.

Rationale–Attachment 1 provides a conceptual layout of the pool water treatment and cooling system and cooling water piping system. The piping layout is not complete. However, distances are based on the dimensions and locations of the WHF pool and equipment in the pool equipment room and mezzanine shown on the WHF general arrangement drawings (References 2.2.2 to 2.2.4and Reference 2.2.6).

Table 2. Estimated Piping Lengths for Pool Water Treatment and Cooling

Node	Length (ft)	Direction	Elevation (ft)
Suction Piping to Pool Water Treatment Pump			
Node 1 (Suction)	5	Up	−8
	34	North	−3
Node 2	66	West	
Node 3	2	Up	
	11	West	−1
Node 4	21	North	
Node 5	39	West	
	13	West	
	14	West	
	5	Up	
Node 6 (Pump Suction)			4
Total	210		4
Discharge Piping through Treatment Train	**Length (ft)**	**Direction**	**Elevation (ft)**
Node 7, Pump Discharge	10	Up	
	18	South	14
	8	Down	
Node 8	15	South	6
Node 9	8	Up	
	26	South	14
	5	Down	
			9
Node 10 (Ion Exchange Inlet)			9
Node 11 (Ion Exchange Outlet)			4
	5	Down	
			−1
Total	95	(use 100 ft)	−1
Discharge Piping to Heat Exchanger	**Length (ft)**	**Direction**	**Elevation (ft)**
	37	East	
Node 12	26	Up	
	16	West	25
Node 29	16	North	
Node 30 (Enter Heat Exchanger)			
Total	98	(Use 100 ft)	25
Discharge Piping from Heat Exchanger to Pool	**Length (ft)**	**Direction**	**Elevation (ft)**
Node 33 (Exit Heat Exchanger)	20	South	25
Node 34	47	East	
	26	Down	
Node 13	16	East	−1
Node 14	16	South	
Node 15	13	East	
Node 16	57	North	
Node 19	20	East	
Node 20	48	Down	
			−49
Total	262	(Use 270 ft)	−49

3.1.6 Estimate for Fittings and Valves

An allowance of 100% of the pipe length is assumed for equivalent pipe lengths for pipe fittings and valves.

Rationale–Adding 50% to 100% of the length to estimate the friction loss through pipe fittings and similar components is recommended when the actual number of fittings has not been established (Reference 2.2.7, p. 36.4). To be conservative 100% is used. This assumption will be revised when the final pipe routing is available.

3.1.7 Estimated Pressure Drops through Equipment

The assumed pressure drops for pool water treatment and cooling equipment are presented in Table 3. These values are used for pressure drop and pump sizing calculations.

Table 3. Pressure Drop for Pool Water Treatment and Cooling Equipment

Equipment	Pressure Drop (psi)
Pump Strainer	1
Roughing Filter (both filter and housing)	25
Polishing Filter (both filter and housing)	30
Ion Exchange Bed	15
Ion Exchange Strainer	1
Heat Exchanger – Shell Side	5
Heat Exchanger – Tube Side	7
Chiller	10

The roughing filters have a 2 micron rating. It is assumed that the underwater filter units have the same rating and a corresponding pressure drop of 25 psi (58.5 ft). The polishing filters have a 0.1 micron rating. It is assumed that the underwater vacuum units have the same rating and a corresponding pressure drop of 30 psi (69.3 ft).

Rationale–The value of 1 psi pressure drop through an in-line strainer is based on typical vendor information. The pressure drops for the roughing and polishing filters are based on maximum differential pressure for loaded filters rather than on clean filters based on typical vendor information. The pressure drop through the ion exchange bed is based on typical vendor data for nuclear ion exchange applications. Pressure drops through shell-and-tube heat exchangers are typical based on a comparison of several heat exchanger vendors. The vendor(s) will supply the actual values when the equipment has been selected.

3.1.8 Pipe Differential Height for Total Head

For the purpose of calculating total head for the pool water treatment and cooling system for various conditions, Table 4 presents the assumed heights of the water at the inlet and discharge locations of the pool water treatment and cooling system.

Table 4. Height of Pool Water at Treatment and Cooling Piping Segments

Location	Elevation (ft)
Suction piping from the pool	−4
Discharge outlet to the pool	−4

Rationale–The pool water level is assumed to be 4 ft below the ground level (Assumption 3.1.2). Although the inlet and outlet piping extend into the pool, the pool is open to the atmosphere; therefore, the height differential is taken from the surface of the pool rather than the actual depth of the piping into the water. The inlet and outlet of the pool water treatment pumps are assumed to be 4 ft above ground level (Assumption 3.1.5, Table 2).

3.1.9 Wet Handling Facility Pool Water Temperature

The average pool water temperature for normal operating conditions is assumed to be 75ºF.

Rationale–An operating temperature of 75ºF is recommended by the BSC Mechanical Heating, Ventilation, and Air-Conditioning (HVAC) group (Reference 2.2.9, p. 2). This is consistent with ANSI/ANS-57.7-1988 (Reference 2.2.10, Section 6.3.2.1) and *Project Design Criteria Document* (PDC) (Reference 2.2.11, Section 4.9.7.5.3) that require an annual average normal pool water operating temperature of 90°F or less and for the normal pool water operating temperature to not exceed 110°F more than 5% of the time, on the average, during the warmest four consecutive months of the year.

3.1.10 Ion Exchange Bed Characteristics

The estimated relative flow rate through the ion exchange bed is assumed to be 7 gpm/ft^3 of resin. The diameter of the bed is calculated assuming a surface loading rate of 25 gpm/ft^2.

Rationale–The relative flow rate is based on typical vendor information for nuclear grade mixed bed resins. Based on *Engineering Design Guide Demineralizer Systems* (Reference 2.2.36, Section 4.2.5, p. 19), a design criterion for mixed bed resins is a surface loading rate of 12 to 25 gpm/ft^2. The actual size of the ion exchange vessel and characteristics of the ion exchange resin will be established when the equipment is procured.

3.1.11 Fuel Rack Capacity

The WHF pool is assumed to hold 120 boiling water reactor (BWR) and 80 pressurized water reactor (PWR) fuel assemblies in the fuel storage racks, one DPC, one transportation, aging, and disposal (TAD) canister, one truck cask, one rail cask, and one TAD canister in remediation.

Rationale–The *Wet Handling Facility Layout Study* (Reference 2.2.8, Section 2.3.2.2) shows storage for 120 BWR and 80 PWR spent nuclear fuel (SNF) assemblies. This exceeds the requirement in *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.12, Section 5.2.4.6) for the WHF to provide a minimum staging capacity of 72 BWR and 48 PWR SNF assemblies. The *Wet Handling Facility Layout Study*

(Reference 2.2.8, p. 17, Figure 4) shows storage for one DPC, one TAD canister, one truck cask, one rail cask, and one TAD canister in remediation.

3.1.12 Heat Load for Fuel Assemblies

The assumed average energy for BWR and PWR fuel assemblies is 0.344 kW and 1.05 kW.

Rationale–This assumption is based on approved DPCs and transportation casks as listed in *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.12, Section 5.2.1.1.4).

Table 5 provides total heat loads and average assembly heat loads for DPCs and truck transportation casks containing BWR and PWR fuel assemblies and identifies the references for the information.

For BWR fuel, legal-weight truck (LWT) cask containing only two assemblies can transport assemblies with greater heat loads than the assumed average. However, transporting only two fuel assemblies per shipment will be infrequent since this will impact the required receipt rate of the WHF.

Table 5. DPC and LWT Heat Loads

Transportation Casks and DPCs	Assemblies	Total Heat Load (kW)	Average kW/Assembly	Reference
PWR	—	—	—	—
GA-4	4	2.468	0.617	Reference 2.2.13, Table 1.2-1
GA-9 (fully loaded)	4	2.180	0.545 (max)	Reference 2.2.14, Table 1.2-2
GA-9 (partially loaded)	2	1.528	0.764 (max)	Reference 2.2.14, Table 1.2-2
NAC-LWT	1	2.5	2.5	Reference 2.2.15, Table 1.2.4
NAC-STC	26	22.1	0.85	Reference 2.2.16, Table 1.2-2
NAC-UMS® Universal Transport Cask	24	20	0.833	Reference 2.2.17, Section 1.2.3
NUHOMS®-MP187	24	13.5	0.764 (max)	Reference 2.2.18, Section 1.2.3.1
Hi-Star 100 Multi-Purpose Canisters (MPC-24)	24 or 32	20	0.833 (0.625 max)	Reference 2.2.19, Tables 1.2.2 and 1.2.3
Fuel Solutions TS-125 (W21 Transportation Canister)	21	22.1	1.05	Reference 2.2.40, Table 1.2.4
BWR				
GA-9 (fully loaded)	9	2.121	0.235 (max)	Reference 2.2.14, Table 1.2-2
GA-9 (partially loaded)	2	1.460	0.730 (max)	Reference 2.2.14, Table 1.2-2
NAC-LWT	2	2.2	1.1	Reference 2.2.15, Table 1.2.4
NAC-UMS® Universal Transport Cask	56	16	0.268	Reference 2.2.17, Section 1.2.3
NUHOMS®-MP197	61	15.9	0.260 (max)	Reference 2.2.38, Section 1.2.3
Transnuclear TN-68	68	21.2	0.313 (max)	Reference 2.2.39, Section 1.2.3
Fuel Solutions TS-125 (W74 Transportation Canister)	64	22	0.344	Reference 2.2.41, Table 1.2.4
Hi-Star 100 Multi-Purpose Canisters (MPC-68)	68	18.5	0.272 (max)	Reference 2.2.19, Tables 1.2.2 and 1.2.3

3.1.13 Cooling Water Temperatures

It is assumed that commercial chillers, dedicated to the pool water and treatment system, provide the cooling water for the heat exchangers at 50ºF and the cooling water is returned at 60ºF.

Rationale–Commercial chillers can provide cooling water over a large range of temperatures. A temperature of 50ºF provides an adequate temperature differential from the pool water temperature for heat transfer.

3.1.14 Heat Exchanger Characteristics

The heat exchangers are assumed to be a single-pass shell-and-tube type with 1-1/4 in. outside diameter tubes (14 gauge) on 1-9/16 in. triangular spacing, 10 ft long.

Rationale–A single-pass heat exchanger is assumed because it more closely represents counter-current flow which provides a more efficient heat transfer when the temperature difference between the cooling water and the water to be cooled is small. The use of triangular spacing will accommodate more tubes than a square pattern. Also, a triangular arrangement produces high turbulence and therefore a high heat transfer coefficient. Because it is a clean system, mechanical cleaning of the tubes is not anticipated. A heat exchanger length of 10 ft is considered a maximum length for floor space considerations, for pressure drop of water in the heat exchanger tubes, and for maintenance operations.

The actual heat exchanger, when selected, could be other than a shell in tube heat exchanger. The actual design of the heat exchanger will be established by a procurement specification. The heat exchanger is sized in this calculation to provide input to the solid model of the WHF.

3.1.15 Air Exchange Rate in Pool Room

The air exchange rate in the WHF pool room is assumed to be 1.2 air changes per hour.

Rationale–This is based on an HVAC calculation, *WHF Heating and Cooling Load Calculation (Confinement Non ITS)* (Reference 2.2.42). The air exchange rate is found by summing the supply air sources (Reference 2.2.42, p.36, Table 4)

$$Supply\ Air = 16130\,{ft^3}/{\min} + 16350\,{ft^3}/{\min} + 3850\,{ft^3}/{\min} = 36330\,{ft^3}/{\min}$$

and dividing by the room volume (Reference 2.2.42, p.60, Appendix A)

$$Room\ Volume = 26100\,ft^2 * 80\,ft = 2088000\,ft^3$$

$$\frac{36330\,{ft^3}/{\min} * 60\,{\min}/{hr}}{2088000\,ft^3} = 1.04\,{changes}/{hr}$$

The use of 1.2 air changes per hour accounts for any unforeseen changes in HVAC supply rates.

3.1.16 Dew Point Temperature for Pool Room

The dew point temperature of the air above the WHF pool is assumed to be 43°F.

Rationale–This is based on an HVAC calculation, *WHF Heating and Cooling Load Calculation (Confinement Non ITS)* (Reference 2.2.42, p. 134, Table G-1).

3.1.17 Pool Makeup Water Flow Rate

Assume that the pool water makeup system can fill the pool at a rate of 200 gpm.

Rationale– It is required that the pool water makeup system provide the capability to add deionized water at a rate faster than the maximum evaporation rate (Reference 2.2.11, Section 4.9.7.5.4). The maximum evaporation rate is 44 gal/hr (Section 6.4.1.2). To maintain a consistent makeup water pipe size between the deionized water system and the pool water makeup system, a make up rate of 200 gpm was selected. This is greater than the maximum evaporation loss rate; therefore, a pool water makeup rate of 200 gpm satisfies this requirement.

3.1.18 Cask Rinse Water

It is assumed that the amount of deionized water added to the pool (used to rinse LWTs and STCs containing DPCs or TAD canisters removed from the WHF pool) averages less than the minimum rate of evaporation of pool water.

Rationale–When LWTs and STCs are removed from the WHF pool, they will be washed down to rinse off contaminated water. This occurs over the WHF pool so the rinse water falls into the pool. If the volume of rinse water exceeds the evaporation rate for the pool, the extra water must be removed from the pool and treated as low-level radioactive waste.

3.1.19 Length of Leak Detection Pipe

It is assumed that the lengths of pipe from the leak detection sump pumps to the WHF pool are the same and are 100 ft.

Rationale–The sumps are located adjacent to the pool (Reference 2.2.2). The height from the leak detection sumps to the WHF pool floor is 56 ft (Assumption 3.1.4). The length of piping is rounded up to 100 ft to account for uncertainty in the piping layout.

3.1.20 Underwater Vacuum Units

It is assumed that five self-contained underwater vacuum units, each with a capacity of 260 gpm, will be used to clean the sides and floor of the WHF pool.

Rationale–The use of four, 260 gpm underwater vacuum units is recommended in *Wet Handling Facility Pool Treatment and Cooling Study* (Reference 2.2.23, Sections 2.2.5 and 4.5). A portion of the crud released from the SNF in the WHF pool will settle rather than being entrained into the pool water treatment and cooling subsystem. Without periodic removal, the crud can be re-entrained by turbulence in the pool water causing a reduction in clarity. Underwater vacuum units are recommended since the pool water provides shielding for the units and the filters can be replaced underwater. One extra vacuum is assumed to accommodate the shelf surface.

3.1.21 Pool Surface Skimmer

A 100 gpm pool skimmer connected by flexible hose to an underwater vacuum unit is assumed to be used for filtering the surface of the WHF pool.

Rationale–The preliminary design for the WHF pool does not include a skimmer built into the pool. A 100 gpm floating pool skimmer is recommended because it is a standard commercially available unit. The 100 gpm floating pool skimmer vacuum units can be connected to any underwater vacuum unit in the WHF pool and can be tethered anywhere in the pool. A self-contained pool skimmer is not recommended because it must be supplied electrical power at the surface of the WHF pool and the filters are changed above water. While the skimmer is in use, the vacuum unit it is connected to will be unavailable for vacuuming operations.

3.1.22 Pool Level Transmitter

Assume a commercially available sonic/radar level transmitter with an accuracy of ±0.1 in. will be used to monitor the pool level and provide alerts when critical levels are reached.

Rationale–According to publicly available information on such equipment, the effective ranges of radar level transmitters are sufficient for this application. Typical transmitters have accuracies no worse than plus or minus 0.1 in. Specific equipment and corresponding performance characteristics will be chosen during the detailed design phase.

3.1.23 Pool Minimum Shielding Level

Assume the minimum pool water shielding level is 35 ft.

Rationale–According to ANSI/ANS-57.7-1988 (Reference 2.2.10, Section 6.1.2.6), the minimum pool water shielding level for the fuel unit storage pool (WHF pool) under normal operations shall be identified. According to *Shielding Calculation for Dry Transfer Facility, Remediation Facility, and Canister Handling Facility* (Reference 2.2.32, Section 5.4.3, p. 45) the minimum allowable water level is 10-1/2 ft above bare fuel. After reviewing the SNF staging rack mechanical equipment envelope (Reference 2.2.33) and the TAD STC mechanical equipment envelope (Reference 2.2.29), the height of the SNF staging racks is 16 ft 9-1/8 in, and the STC is 20 ft. When an STC is in the pool, it sits on a 2 ft thick crush pad. This means the top of the STC is 22 ft above the pool floor. The total height needed for shielding is found by adding the bare fuel height (22 ft) to the minimum water level (10-1/2 ft).

$$Minimum\ Shielding\ Height = 10.5\,ft + 22\,ft = 32.5\,ft \quad \text{(Use 35 ft)}$$

The exact level will be determined during the detailed design phase.

3.1.24 Resin Sluicing Piping Length

The dimensions and elevations of the resin handling system pipes are as shown on Attachment 3. Assume the total length of sluicing piping is 145 ft (105 ft suction and 40 ft discharge) and the total length of the recirculation path is 156 ft (105 ft suction and 51 ft discharge).

Rationale–These values are based on the piping layout shown in Attachment 3. The figures in Attachment 3 are based on the *Wet Handling Facility General Arrangement Ground Floor Plan* (Reference 2.2.2). This assumption will be verified during the detailed design phase.

3.1.25 Vendor Supplied Dewatering System

Assume that the spent resin is pumped outside of the WHF to a vendor supplied and operated dewatering system.

Rationale–A private vendor will be contracted to perform dewatering and disposal of the resin once it is removed from inside the WHF. This assumption will be verified once a vendor has been selected.

3.1.26 Ion Exchanger

The detailed design of the ion exchanger will be preformed by the selected vendor.

Rationale–The ion exchanger will be procured. The details of all items contained by the ion exchanger (fluidization headers, resin retention screens, flow distributor) will also be specified by the vendor.

3.1.27 Borated Water Makeup System

Assume the borated makeup water is added to the pool treatment system at the pool treatment water return pipe.

Rationale–This is consistent with the *Pool Water Boron Makeup System Calculation* (Reference 2.2.35, Assumption 3.1.7). This point will facilitate mixing.

3.1.28 Resin Void Space

Assume the resin bed volume is 33% void space.

Rationale–According to the *Nuclear Engineering Design Guide for Spent Resin Handling Systems* (Reference 2.2.34, Section 4.2), the water volume occupying the resin void space is approximately 33% to 40% of the resin bed volume. Because the resin concentration of the slurry cannot exceed 40% by volume (Reference 2.2.34, Section 4.2), 33% void space results in a higher volume of resin to be sluiced and therefore is the more conservative estimate.

3.1.29 Fluidizing Flow Rate

Assume the required flow rate for resin bed fluidization is 2.5 gpm/ft^2.

Rationale–According to the *Nuclear Engineering Design Guide for Spent Resin Handling Systems* (Reference 2.2.34, Section 4.4), an upward flow of 1.5-2.5 gpm/ft² should be provided for resin fluidization. For conservatism, this calculation will use 2.5 gpm/ft². This assumption will be verified during detailed design.

3.1.30 Fluidized Resin Pressure Drop

Assume the pressure drop through fluidized resin is 55% higher than that of water.

Rationale–According to the *Nuclear Engineering Design Guide for Spent Resin Handling Systems* (Reference 2.2.34, Section 4.3), the pressure drop of resin slurry is 55% higher than that of water. The fluidized resin in the ion exchanger is the same composition as the resin slurry being sluiced through the piping, so the pressure loss will be similar.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Density of Water and Borated Water

The density of water and borated water over the range of temperatures considered in this calculation is assumed to be 62.4 lb/ft^3 (1 gram/ml).

Rationale–The density of water is consistent in the temperature range from 32ºF to 100ºF (Reference 2.2.20, p. F-11), varying by less than 1% over that temperature range. For a 2000 to 2500 ppm boron solution (Reference 2.2.12, p. 249, Section 32.2.1.1), the boric acid solution is less than 2% wt. Therefore, this will not significantly affect the density of the water.

3.2.2 Heat Transfer Coefficient for Heat Exchanger

The overall heat-transfer coefficient for a shell and tube heat exchanger using deionized water is assumed to be 300 Btu/ºF-ft^2-hr.

Rationale–Typical overall heat-transfer coefficients with deionized water-shell side and pool water-tube side is 300 to 500 Btu/ºF-ft^2-hr (Reference 2.2.5, p. 10-39, Table 10-10). The use of 300 Btu/ºF-ft^2-hr is bounding because it results in a larger heat exchanger.

3.2.3 Heat Capacity of Water and Borated Water

The heat capacity (C_p) of water and borated water is assumed to be 1 Btu/lb-ºF (1 cal/g-ºC) over the range of temperatures considered in this calculation.

Rationale–The heat capacity of water is consistent in the temperature range from 32ºF to 100ºF (Reference 2.2.5, Table 3-176), varying by less than 1% over that temperature range. For a 2000 to 2500 ppm boron solution (Reference 2.2.12, p. 249, Section 32.2.1.1), the boric acid solution is less than 2% wt. Therefore, this will not significantly affect the density of the water.

3.2.4 Minimum Water Vapor Pressure for Pool Room

The minimum vapor pressure for water in the air above the WHF pool exists when the air is absolutely dry (0 in. Hg).

Rationale–This is the worst-case scenario for evaporation of water from the WHF pool, because it results in the absolute maximum evaporation of water from the pool.

3.2.5 Dimensions for a Shielded Transfer Cask

For calculating the volumes of the TAD canister STC and the DPC STC, the casks are assumed to be right cylinders 22 ft high and 9 ft in diameter.

Rationale–The STCs are cylindrical containers on a square, relatively hollow base. The TAD canister STC and the DPC STC each have a maximum height of 22 ft and a maximum diameter of 9 ft, as shown on *Wet Handling Facility TAD Shielded Transfer Cask Mechanical Equipment Envelope* (Reference 2.2.29) and *Wet Handling Facility Vertical DPC STC Mechanical Equipment Envelope Sheet 1 of 2* (Reference 2.2.30). Assuming that the square base is a solid cylinder simplifies the calculation and is conservative.

3.2.6 Maximum Pool Water Leakage Rate

The maximum rate of pool water leakage to the leak detection sump is assumed to be 15 gpm should a leak occur.

Rationale–The design requirements of ANSI/ANS-57.7-1988 (Reference 2.2.10, Sections 6.1.2.2 and 6.1.2.3) require that the pool be able to withstand, without loss of functional integrity, the impact of the maximum load over the pool, dropped into the pool from the highest position attainable by the load. A rate of 15 gpm is conservative based on *Storage of Water Reactor Spent Fuel in Water Pools, Survey of World Experience* (Reference 2.2.21, Section 7.2.1), which indicates that liner leakage has been minimal in existing fuel pools, generally amounting to a few liters per day.

3.2.7 Dimensions for a Shielded Transfer Cask

For calculating the volumes of the TAD canister STC and the DPC STC, the casks are assumed to be right cylinders 22 ft high and 9 ft in diameter.

Rationale–The STCs are cylindrical containers on a square, relatively hollow base. The TAD canister STC and the DPC STC each have a maximum height of 22 ft and a maximum diameter of 9 ft, as shown on *Wet Handling Facility TAD Shielded Transfer Cask Mechanical Equipment Envelope* (Reference 2.2.29) and *Wet Handling Facility Vertical DPC STC Mechanical Equipment Envelope Sheet 1 of 2* (Reference 2.2.30). Assuming that the square base is a solid cylinder simplifies the calculation and is conservative.

3.2.8 Vapor Pressure of Water and Borated Water

The vapor pressure of water and borated water is assumed to be 0.42964 psia over the range of temperatures considered in this calculation.

Rationale–The vapor pressure for water at temperature of 75°F (Assumption 3.1.9) is 0.42964 psia (Reference 2.2.20, p. E 23). For a 2000 to 2500 ppm boron solution (Reference 2.2.12, p. 249, Section 32.2.1.1), the boric acid solution is less than 2% wt. Therefore, this will not significantly affect the vapor pressure of the water.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This document is prepared in accordance with EG-PRO-3DP-G04B-00037 (Reference 2.1.1). The pool water treatment and cooling system is classified as non-ITS (non-important to safety) as documented in *Preliminary Preclosure Safety Classifications of SSCs* (Reference 2.2.22, Appendix A, p. A-16) and in *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.12, Section 32.1.2). Therefore, the approved version is designated QA: NA.

4.2 USE OF SOFTWARE

None.

4.3 CALCULATION APPROACH

The calculation is broken up into six subsections:

- Pool Equipment Sizing
- Spent Resin Handling and Equipment Sizing
- Heat Exchanger and Chiller Sizing
- Pool Water Control and Makeup
- Leak Detection Equipment Sizing
- Pool Cleaning Equipment Sizing

The calculation approach for each subsection is described in Sections 4.3.1 through 4.3.6.

4.3.1 Pool Equipment Sizing

- **Pool Volume**–Utilizing the general arrangement drawings for the WHF pool, the volume is calculated for the total pool, the DPC unloading bay, and the combined fuel transfer and fuel staging areas.

- **Flow Rates**–Based on the pool volumes and utilizing the assumptions for pool turnover times, the required flow rates for the treatment system and underwater filters are calculated.

- **Number of Trains**–This selection establishes the number of pool water equipment trains.
- **Underwater Filters**–This section documents the number and location of the underwater filters. Flow rates will be based on required rates calculated previously.
- **Pipe Sizing**–Based on the calculated flow rates, pipe sizes for the treatment trains are selected.
- **Equipment Sizing**–Based on the flow rates and assumptions for the treatment equipment, the equipment is sized. This sizing includes the:
    - Treatment pump strainers (pressure drop and flow rate)
    - Treatment pumps (flow rate, total dynamic head (TDH), hydraulic and motor horsepower, and net positive suction head)
    - Roughing filters (flow rate, size, rating, and pressure drop)
    - Polishing filters (flow rate, size, rating, and pressure drop)
    - Ion exchange vessels (flow rate, volume of resin, diameter of vessel, resin depth, and pressure drop)
    - Ion exchange strainers (pressure drop and flow rate).

4.3.2 Spent Resin Handling and Equipment Sizing

- **Description of Operation**–A brief description of the proposed operation for sluicing and transferring the ion exchange resin is provided.
- **Slurry Volume**–Calculate final slurry volume and required volume of pool water needed for fluidization and transfer.
- **Pipe Sizing**–Determine pipe sizing for piping required for resin fluidization and transfer.
- **Spent Resin Pump Sizing**–Determine the flow rate, TDH, hydraulic and motor horsepower, and net positive suction head for the spent resin transfer pump.

4.3.3 Heat Exchanger and Chiller Sizing

- **Heat Load**–Determine the maximum heat load in the WHF pool.
- **Heat Transfer Area**–Based on the calculated heat load and the relevant design assumptions, determine the required heat transfer area for the heat exchangers.
- **Cooling Water Flow**–Based on the calculated heat load and the relevant design assumptions, determine the required cooling water flow rate for the heat exchangers.

- **Pipe Sizing**–Determine pipe sizing for cooling water piping.
- **Heat Exchanger Selection**–Describe the selected heat exchanger type.
- **Size Chillers**–Determine the size of the chillers (in tons of refrigerant) based on the calculated heat load.
- **Cooling Water Pump Sizing**–Determine the TDH, hydraulic and motor horsepower, and net positive suction head for the cooling water pumps.

4.3.4 Pool Water Control and Makeup

- **Evaporative Losses**–Calculate the expected evaporative losses from the WHF pool.
- **Displacement Volume**–Calculate the displacement volume for the legal weight truck (LWT) casks and the STC when placed in the WHF pool.
- **Water Accumulation**–Describe the expected accumulation rate of water into the WHF pool from cask rinsing/decontamination operations.
- **Deionized Water Supply**–Determine the required flow rate of deionized water necessary to replace pool water lost and the piping size.
- **Borated Water Makeup**–Determine routing for the borated makeup water supply piping. The description of the borated water makeup system is included in a separate calculation.
- **Pool Level Monitoring**–Describe the proposed WHF pool monitoring system including control levels.

4.3.5 Leak Detection Equipment Sizing

- **Description of Operation**–Provide a brief description of the proposed design and operation for the WHF pool leak detection system.
- **Pipe Sizing**–Determine pipe sizing for the leak detection sump pumps.
- **Sump Pump Sizing**–Determine the TDH, hydraulic and motor horsepower, and net positive suction head for the sump pumps.

4.3.6 Pool Cleaning Equipment Sizing

Description of Operation–Provide a brief description of the proposed design and operation for the WHF pool vacuums and skimmer. The description will include the sizing basis and proposed locations for the vacuums and skimmer.

5. LIST OF ATTACHMENTS

6. BODY OF CALCULATION

6.1 POOL WATER TREATMENT SUBSYSTEM

The purpose of the pool water treatment subsystem is to maintain the quality of the water in the pool. This includes radioactivity, clarity, conductivity, and water chemistry as identified in the PDC (Reference 2.2.11, Section 4.9.7.5.2). The following items are addressed in this section:

- Volume of water in the WHF pool areas
- Flow rate for pool water treatment trains
- Number, location, and usage of treatment trains
- Sizing of underwater filter units
- Pipe sizing
- Pump strainer pressure drop
- Pool water treatment pump sizing
- Filter sizing
- Ion exchange vessel sizing
- Ion exchange resin strainer pressure drop.

6.1.1 Volume of Pool Areas

The dimensions for the WHF pool are shown on Figure 1 (Assumption 3.1.2). The volumes of structural features in the pool are calculated and subtracted from the gross area of the pool. Table 6 presents the calculations for determining the volume of the pool and individual components using the equation for the volume of rectangular solids (Equation 1):

$$Volume = Length * Width * Depth \tag{Eq. 1}$$

Table 6. Total Volume of Pool Water

Space	Length (ft) East-West	Width (ft) North-South	Height (ft)	Volume (ft^3)
Gross Pool	75	61	48	219,600
Items in Pool				
Staging Shelf	17	59	18	18,054
Fuel Rack Wall	2	43	20	1,720
DPC Unloading Bay Wall	2	18	48	1,728
DPC Unloading Bay Wall	58	2	48	5,568
Total Volume of Items in Pool				27,070

Total Pool Water = 219,600 ft – 27,070 ft
= 192,530 ft^3
= 1,440,300 gal (Use 1,440,000 gal) (7.481 gal/ft^3)

Find the volume of the DPC unloading bay using the dimensions shown on Figure 1 (Assumption 3.1.2); Table 7 presents the calculation data to determine the volume of DPC cutting and individual components using Equation 1:

Table 7. Volume of DPC Unloading Bay Water

Space	Length (ft) East-West	Width (ft) North-South	Height (ft)	Volume (ft^3)
Gross Pool Area	58	16	48	44,544
Items in Pool				
Staging Shelf	17	16	18	4,896

DPC Pool Water = 44,544 ft^3 – 4,896 ft^3
= 39,648 ft^3
= 296,607 gal (Use 300,000 gal) (7.481 gal/ft^3)

Find volume of fuel transfer and fuel staging area.

Fuel Transfer and Fuel Staging Area Water = Total Pool Water – DPC Pool Water
= 1,440,000 gal – 300,000 gal
= 1,140,000 gal

6.1.2 Pool Water Treatment Subsystem Flow Rate

6.1.2.1 72 Hour Turnover Rate

The pool turnover requirement for the entire WHF pool is 72 hr or less (Reference 2.2.11, Section 4.9.7.5.1). Each treatment train will be sufficient to meet the 72 hr turnover requirement. Thus:

Flow Rate = 1,440,000 gal/72 hr
= 20,000 gal/hr
= 333 gal/min (Use 350 gpm)

A flow rate of 350 gal/min is used for each of the treatment trains of the pool water treatment subsystem.

6.1.2.2 24 Hour Turnover Rate

The fuel transfer and fuel staging area has an operating assumption for 24 hr turnover for filtration (Assumption 3.1.1). A 600 gpm underwater filter is selected to meet the turnover requirement. The fuel transfer and fuel staging area has 1,140,000 gal of water (Section 6.1.1). The 350 gpm treatment train and the 600 gpm underwater filter provide a turnover rate of 20 hr:

$$Turnover = \frac{1{,}140{,}000\,gal}{(350+600)\dfrac{gal}{\min}} * \frac{hr}{60\min} = 20hr$$

6.1.3 Number, Location, and Usage of Treatment Trains

One treatment train serves the fuel transfer and fuel staging areas and a separate treatment train is used for the DPC unloading bay (Reference 2.2.8, Section 2.3.3.3). A third train serves as backup for the first two systems. Based on the cooling needs of the WHF pool, the discharge from the pool water treatment subsystem will either be directed to the pool water cooling subsystem or be returned directly to the WHF pool. According to ANSI/ANS-57.7-1988 (Reference 2.2.10, Section 6.3.2.7) the pool water cleanup system need not be run continuously so long as it satisfies all other governing criteria.

6.1.4 Underwater Filters

As calculated in Section 6.1.2.2, 600 gpm underwater filters (050-PW00-SKD-00001A, B, C, and D) in conjunction with a single train at 350 gpm are suitable to meet the 24 hr filtration turnover assumption (Assumption 3.1.1). The 600 gpm underwater filters are commercially available and are designed for use in nuclear fuel pools. The pressure loss across the underwater filters is 25 psi or 58.5 ft (Assumption 3.1.7). Two underwater filters are placed in both the DPC unloading bay and the fuel transfer area. The second filter in each area is available during filter change out of the first. These underwater filters should be placed in close proximity to where the LWTs and DPCs are opened and where crud bursts are most likely to occur. In doing so, much of the crud released by opening the casks and moving the spent fuel can be captured before it spreads throughout the entire pool.

The hydraulic horsepower for a pump is calculated using the total dynamic head (H in ft), the specific gravity of the liquid being pumped (s = 1.0 [Assumption 3.2.1]), and the flow rate of liquid as shown in Equation 2 (Reference 2.2.5, Equation 6-1):

$$Hydraulic\ hp = \frac{8.33Hs(gal/\min)}{33{,}000} \qquad \text{(Eq. 2)}$$

$$Hydraulic\ hp = \frac{8.33 * 58.5 * 1 * 600}{33{,}000} = 8.9hp$$

The pump efficiency is calculated as shown in Equation 3 (Reference 2.2.5, Equation 6-4):

$$Pump\ efficiency = \frac{hydraulic\ hp}{brake\ hp} \qquad \text{(Eq. 3)}$$

Rearranging Equation 3, the brake horsepower of the pump is calculated by dividing the hydraulic horsepower of the pump by the pump efficiency. The pump efficiency is 60% (Assumption 3.1.3):

$$Brake\ hp = \frac{8.9hp}{60\%} = 14.8hp \qquad \text{(Use 15 hp)}$$

6.1.5 Treatment System Pipe Sizes

Table 8 presents the pressure drop per 100 ft of Schedule 40 pipe at flow rates of 175 gpm, 350 gpm, and 700 gpm for possible pipe sizes (Reference 2.2.24, p. B-14). Based on the pressure drops for the given flow rates, 6 in. pipe is selected for supply and return piping from the pool to the treatment trains. For piping through the treatment trains, 4 in. Schedule 40 pipe (Reference 2.2.43, Attachment 1) is chosen.

Table 8. Relative Pressure Drops for Piping

From	To	Flow Rate (gpm)	Pipe Diameter	Pressure Drop (psi/100 ft pipe)	Velocity (ft/sec)
WHF Pool	Pump Header	Two trains 700	6 in.	1.35	7.78
		(Section 6.1.2.1)	4 in.	Not Shown	
		One Train 350	6 in.	0.367	3.89
		(Section 6.1.2.1)	4 in.	2.84	8.82
Treatment Pumps	Filters	175	4 in.	0.774	4.41
		(Section 6.1.8)	3 in.	3.00	7.60
Filters	Ion Exchange Vessels	350	4 in.	2.84	8.82
		(Section 6.1.2.1)	3 in.	Not Shown	
Ion Exchange Vessels	Heat Exchanger	Two trains 700	6 in.	1.35	7.78
		(Section 6.1.2.1)	4 in.	Not Shown	
Heat Exchanger	Return Header	350	6 in.	0.367	3.89
		(Section 6.1.2.1)	4 in.	2.84	8.82
Return Header	WHF Pool	350	6 in.	0.367	3.89
		(Section 6.1.2.1)	4 in.	2.84	8.82

6.1.6 Treatment Pump Strainers

Strainers (050-PW00-STR-00001A, B, and C) are used to remove solid particles that have the potential to damage the treatment train pumps. The DPC cutting station, while located outside the pool, may still be a source for metal shavings that may be generated by cutting open DPCs. The choice of strainer will be based on recommendations from the pump manufacturer. A pressure loss of 1 psi is assumed for the strainers (Assumption 3.1.7). The strainers are designed for a flow rate of 350 gpm.

6.1.7 Treatment Pumps

The pool water treatment pumps (050-PW00-P-00001A, B, and C) provide the motive force to take water from the WHF pool, send it through the pool water treatment and cooling system, and return the water to the pool.

Centrifugal pumps were chosen for their simplicity, uniform flow, and low initial and maintenance costs. Although positive displacement pumps have higher over-all efficiencies than centrifugal pumps, the discharge from a positive displacement pump surges and the pumps have more moving parts. Positive displacement pumps rely on tight clearances between moving parts while a centrifugal pump is more tolerant of particulates (Reference 2.2.5, Section 6).

6.1.7.1 Sizing Pump for Operating Conditions

The total head for the piping system is used to determine the horsepower requirements of the pump. The total head is calculated using the Bernoulli equation for non-compressible fluid (Reference 2.2.24, Equation 3.1):

$$H = 144\left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}\right) + (Z_2 - Z_1) + \left(\frac{v_2^2 - v_1^2}{2g}\right) + h_L \qquad \text{(Eq. 4)}$$

where

H	=	total head, feet of fluid	
$P_2 = P_1$	=	pressure at end and beginning of piping system, psi	(both at pool)
$\rho_2 = \rho_1$	=	density of borated water, 62.4 lb/ft^3	(Assumption 3.2.1)
$Z_2 = Z_1$	=	height at end and beginning of piping system, ft	(Assumption 3.1.8)
$v_2 = v_1$	=	mean velocity, ft/sec	(stagnant at pool)
g	=	acceleration due to gravity, 32.2 ft/sec^2	
h_L	=	head loss due to friction, feet of fluid	

For this piping system, the Bernoulli equation simplifies to:

$$H = h_L$$

Using the piping arrangement in Attachment 1, the piping goes from the WHF pool to the pool water treatment pump, through the cooling subsystem, and back to the pool. The head losses for this arrangement are presented in Table 9. The pressure drop through pipe is taken from *Flow of Fluids through Valves, Fittings, and Pipe* (Reference 2.2.24, p. B-14). The length of pipe between equipment and the pressure drops through equipment are based on Assumptions 3.1.5 (Table 2) and 3.1.7. For pipe fittings and valves, the equivalent length of piping is double the piping length (Assumption 3.1.6).

Table 9. Head Loss for Pool Water Treatment and Cooling Piping

Piping and Equipment	Length (ft)	Equivalent Length w/Fittings (ft)	Pressure Drop (psi/100 ft)	Pressure Drop (psi)	Head Loss (ft)	Assumption
Suction						
6 in. Schedule 40 pipe (700 gpm)	210	420	0.367	1.5	3.5	Assumption 3.1.5
Pump Strainer				1.0	2.3	Assumption 3.1.7
Discharge						
4 in. Schedule 40 pipe (350 gpm)	100	200	2.84	5.7	13.2	Assumption 3.1.5
Roughing Filter				25	57.8	Assumption 3.1.7
Polishing Filter				30	69.3	Assumption 3.1.7
Ion Exchange				15	34.7	Assumption 3.1.7

Table 9. Head Loss for Pool Water Treatment and Cooling Piping (Continued).

Piping and Equipment	Length (ft)	Equivalent Length w/Fittings (ft)	Pressure Drop (psi/100 ft)	Pressure Drop (psi)	Head Loss (ft)	Assumption
Ion Exchange Strainer				1	2.3	Assumption 3.1.7
6 in. Schedule 40 pipe (700 gpm)	100	200	0.367	0.7	1.6	Assumption 3.1.5
Heat Exchanger				7	16.2	Assumption 3.1.7
6 in. Schedule 40 pipe (700 gpm)	270	540	0.367	2.0	4.6	Assumption 3.1.5
Total				88.9	205.3	

Therefore:

$$H = h_L = 205.3\,ft \qquad (88.9\text{ psi})$$

The specific gravity, *s*, of borated water is 1.0 (Assumption 3.2.1) and the flow rate of the pool water treatment subsystem is 350 gpm (Section 6.1.2.1). The hydraulic horsepower for a pump is calculated using Equation 2:

$$Hydraulic\ hp = \frac{8.33Hs(gal/\min)}{33{,}000}$$

$$Hydraulic\ hp = \frac{(8.33 * 205.3\,ft * 1 * 350\,gal/\min)}{33{,}000} = 18.1hp$$

The pump efficiency is calculated using Equation 3:

$$Pump\ efficiency = \frac{hydraulic\ hp}{brake\ hp}$$

Rearranging Equation 3, the brake horsepower of the pump is calculated by dividing the hydraulic horsepower of the pump by the pump efficiency. The pump efficiency is 60% (Assumption 3.1.3):

$$Brake\ hp = \frac{18.1hp}{60\%} = 30.2hp \qquad \text{(Use 35 hp)}$$

6.1.7.2 Pump Horsepower

Based on the condition analyzed in Sections 6.1.7.1, the horsepower for the pool water treatment and cooling system should be a minimum of 35 hp. However, with the large number of assumptions, a standard motor size of 40 hp is recommended.

6.1.7.3 Net Positive Suction Head Available

The net positive suction head available ($NPSH_A$) is calculated using Equation 5 (Reference 2.2.25, p. 1-11):

$$NPSH_A = h_a - h_{vpa} \pm h_{st} - h_{fs} \qquad \text{(Eq. 5)}$$

where

h_a = absolute pressure (ft of water)
h_{vap} = vapor pressure of liquid (ft)
h_{st} = static head (ft)
h_{fs} = all suction line losses due to friction

Standard atmospheric pressure at Mercury, Nevada, is 13.021 psia according to *2001 ASHRAE Handbook, Fundamentals* (Reference 2.2.26, p. 27.14, Table 1A). The PDC (Reference 2.2.11, Section 4.9.2.3.1) states that data for Mercury, Nevada, provided in *2001 ASHRAE Handbook, Fundamentals* (Reference 2.2.26) can be used for outdoor design conditions. The absolute pressure in feet of water is found by dividing by the density of borated water 62.4 lb/ft^3 (Assumption 3.2.1):

$$h_a = \frac{13.021\,\frac{lb}{in^2}}{62.4\,\frac{lb}{ft^3}} * \left(\frac{12in}{ft}\right)^2 = 30\,ft$$

The saturated vapor pressure of water at 75°F (Assumption 3.1.9) is 0.42964 psi (Reference 2.2.20, p. E-23). This is converted to feet of water by dividing by the density of water:

$$h_{vap} = \frac{0.42964\,\frac{lb}{in^2}}{62.4\,\frac{lb}{ft^3}} * \left(\frac{12in}{ft}\right)^2 = 0.99\,ft \quad \text{(Use 1 ft)}$$

The static head from the pool water surface to the pump centerline is a total of −8 ft (Assumptions 3.1.5 and 3.1.8), therefore:

$$h_{st} = -8\,ft$$

The suction losses from the pool to the treatment pumps are taken from Table 9:

$$h_{fs} = (3.5 + 2.3)ft = 5.8\,ft$$

Thus, the $NPSH_A$ is:

$$NPSH_A = 30ft - 1ft - 8ft - 5.8ft = 15.2ft \quad \text{(Use 15 ft)}$$

6.1.8 Roughing and Polishing Filters

For each treatment train, two filters will be used for roughing filters and two for polishing. The flow will be divided between the two parallel filters so that each has a flow rate of 175 gpm. The filters are expected to be 40 in. long and 6 in. in diameter, which is consistent with nuclear filters from several manufactures.

The roughing filters (050-PW00-FLT-00001A, 050-PW00-FLT-00003A, 050-PW00-FLT-00005B, 050-PW00-FLT-00007B, 050-PW00-FLT-00009C, and 050-PW00-FLT-00011C) have a first layer for 20 micron particles and a second layer for 2 micron particles. The dual nature of this type of filter reduces the pressure drop across the filter as it becomes loaded. The roughing filters have an assumed pressure drop of 25 psi (Assumption 3.1.7).

The polishing filters (050-PW00-FLT-00002A, 050-PW00-FLT-00004A, 050-PW00-FLT-00006B, 050-PW00-FLT-00008B, 050-PW00-FLT-00010C, and 050-PW00-FLT-00012C) will be 0.1 micron. Individual crud particles can be as small as 0.1 micron (Reference 2.2.27, p. iv). The 0.1 micron filter will also remove any bacteria or algae from the water. The polishing filters have an assumed pressure drop of 30 psi (Assumption 3.1.7).

6.1.9 Ion Exchange Vessels

The ion exchange vessels (050-PW00-IX-00001A, B, and C) are filled with a mixed bed resin to remove radioactive ions such as ^{60}Co, ^{137}Cs, and ^{90}Sr from the pool water. The mixture will be composed in such a manner as to prevent removal of boron.

The ion exchange vessels also maintain water quality as required by the PDC (Reference 2.2.11, Section 4.9.7.5.2):

- Provide for an annual average pool water conductivity less than 3 micro-mho/cm.
- Ensure that water chloride concentration is less than 0.5 ppm.
- Ensure that average pool water pH is between 5.3 and 7.5.

In accordance with Assumption 3.1.10, the volumetric flow rate through the ion exchange bed is 7 gpm/ft^3 of resin. At a system flow rate of 350 gpm (Section 6.1.2.1), 50 ft^3 of resin is needed. With a surface loading rate of 25 gpm/ft^2 (Assumption 3.1.10) the required surface area and corresponding diameter are:

$$Surface\ Area = \frac{350 gpm}{25 \dfrac{gpm}{ft^2}} = 14.0 ft^2$$

$$Diameter = 2\sqrt{\frac{14.0\,ft^2}{\pi}} = 4.2\,ft \quad \text{(Use 5ft)}$$

With a 5 ft diameter the actual surface loading rate is:

$$Surface\ Loading\ Rate = \frac{350\,gpm}{(5\,ft)^2\,\pi/4} = 17.8\,\frac{gpm}{ft^2}$$

Using the volume of resin and a bed diameter of 5 ft, the depth of the ion exchange column is calculated using the formula for the volume of a right cylinder (Equation 6):

$$Volume = Height * \pi\left(\frac{Diameter}{2}\right)^2 \tag{Eq. 6}$$

$$Height = \frac{Volume}{\pi\left(\frac{Diameter}{2}\right)^2} = \frac{50}{\pi\left(\frac{5}{2}\right)^2} = 2.5\,ft$$

With a bed height of 2.5 ft, the distance between resin screens, including 100% freeboard (Reference 2.2.36, Section 4.2.5, p. 14), is estimated to be 5 ft. Adding 15 in. each for the curve of the pressure vessel head and bottom and a 6 in. allowance for distribution systems, results in an estimated ion exchanger height of 8 ft.

The ion exchanger vessel has an assumed pressure drop of 15 psi (Assumption 3.1.7).

6.1.10 Strainer for Resin

For nuclear grade ion exchange resin, about 95% of the beads are 0.3 to 1.2 mm. However, smaller, broken or misshapen ion exchange beads can slip through the screening at the bottom of the ion exchange vessel. Strainers (050-PW00-STR-00002A, B, and C) are used to ensure that ion exchange resin is not sent to the pool. The strainers are not expected to develop a significant radiation field since the filters and ion exchange resin have removed essentially all of the contamination in the processed pool water. Pressure loss through the strainer is 1 psi (Assumption 3.1.7). The strainers are designed for a flow rate of 350 gpm.

6.2 SPENT RESIN HANDLING

The resin inside the ion exchangers will need to be replaced periodically based on radiation levels or the pressure drop across the ion exchanger. This is accomplished through a sluicing process. A mixture of resin and borated water will be pumped directly from the ion exchangers into a vendor supplied dewatering system and then ultimately transported off site by the vendor for disposal (Assumption 3.1.25). During dewatering, the returned sluice fluid will be routed to a C3 drain and into the low-level (radioactive) waste collection system. A schematic of this process is shown in Figure 2.

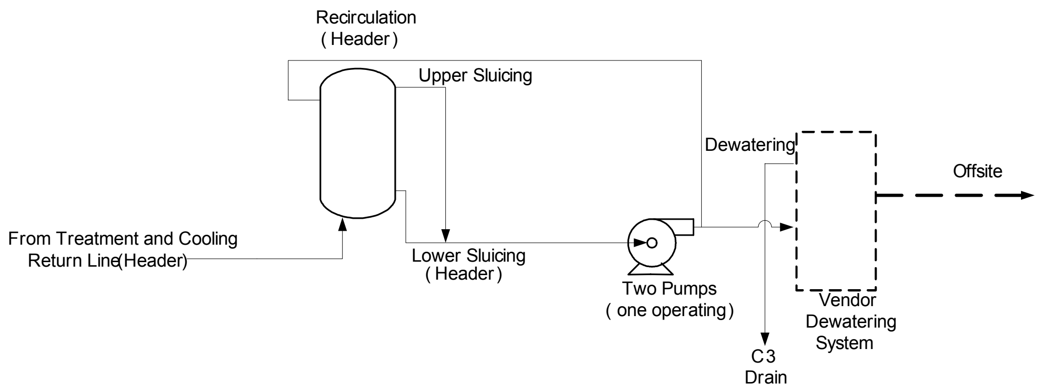


Figure 2. Resin Sluicing Schematic

The conceptual layout for the resin handling system is shown in Attachment 3. The current pool treatment system configuration consists of three separate trains. Each train has a complete set of treatment equipment. This means that three separate ion exchangers will need to be sluiced. To accomplish this, piping from each ion exchanger will be combined to a lower sluicing pipe via a header. Two pumps will be connected in parallel to the lower sluicing pipe and isolation valves will be used to facilitate operation of one pump at a time (the second pump is redundant). The pump discharge will be routed through the lower sluicing pipe to the vendor supplied dewatering system (Assumption 3.1.25). Only one ion exchanger will be sluiced at a time in order to keep two in operation.

Before the resin can be sluiced, it needs to be fluidized. This is accomplished using borated water from the pool treatment return pipe, tapped from the return line prior to the heat exchangers. The pool water will be distributed through a header to the bottom of the ion exchanger. This flow of water will serve to agitate the resin, break up any agglomeration, and set it into a state of suspension. The water that fluidizes the resin will be discharged from the ion exchanger through an upper sluicing pipe. This pipe will exit the ion exchanger and connect with the lower sluicing line (upstream of the transfer pump). The water will then be pumped to the vendor supplied dewatering system (Assumption 3.1.25) for disposal. The details for this equipment will be provided by the vendor (Assumption 3.1.26).

Recirculation pipe will run from the lower sluicing pipe (downstream of the transfer pump) back to the ion exchanger. This line will be utilized only in the case that the slurry needs to be diverted while the vendor is dewatering. The slurry flow should not be stopped because the resin will settle and clog the pipes. When there is sufficient available volume, the recirculation path will be closed and the slurry will be routed to the vendor supplied dewatering system.

This section of the calculation covers the sizing of the pipes and pump for this system. The steps for performing this task are as follows:

- Determine the amount of slurry to be transferred.
- Calculate the volume of borated water needed to create slurry (per design guide).
- Determine the minimum flow rate necessary to maintain the resin in suspension.
- Determine the lengths of piping.
- Size the piping (per design guide).

- Calculate the total head loss.
- Size the pumps according to flow rates and head losses.

6.2.1 Spent Resin Slurry Volume

The area between the resin screens of the ion exchangers is a right cylinder of 5 ft height and 5 ft diameter (Section 6.1.9). This volume is calculated, using Equation 6.

$$Volume = \pi\left(\frac{5\,ft}{2}\right)^2 5\,ft = 98\,ft^3$$

As discussed in Section 6.1.9, the volume of the resin bed to be kept in each ion exchanger is 50 ft^3.

According to the *Nuclear Engineering Design Guide for Spent Resin Handling Systems* (Reference 2.2.34, Section 4.2), the concentration of resin in the slurry should not exceed 40% by volume. The necessary amount of water in the ion exchanger for sluicing is determined using Equation 7. The total water volume between the screens is determined by adding the freestanding water volume to the water volume occupying the resin void space. The water volume occupying the resin void space is 33% of the resin bed volume (Assumption 3.1.28). This gives an actual resin volume of 34 ft^3 (50 ft^3 * (1-0.33)).

$$V_{slurry} = \frac{V_{resin}}{0.4} = \frac{34\,ft^3}{0.4} = 85\,ft^3 \qquad \text{(Eq. 7)}$$

The tank has capacity of 98 ft^3, so the slurry will have a sufficiently low concentration of resin.

6.2.2 Resin Fluidization Pipe

Before sluicing can begin, the resin must be fluidized. This consists of agitating the resin until it is suspended in the borated water. This will be accomplished by routing borated water from the treatment system return pipe through a header at the bottom of the ion exchanger. Should the pressure of the borated water in the pipe not be sufficient to adequately fluidize the resin, compressed air may be routed through the same header. The details as to the hardware for this process will be provided by the vendor (Assumption 3.1.26).

The borated water needs to enter the ion exchanger with sufficient velocity to fluidize the resin into suspension. The required flow rate for this velocity is 2.5 gpm/ft^2 (Assumption 3.1.29). The flow rate required through the piping *(Q_{PIPE})* is found using Equation 8:

$$Q_{PIPE} = Q_{FLUIDIZE} * A_{EXCHANGER} \qquad \text{(Eq. 8)}$$

where

$Q_{FLUIDIZE}$ = upward fluidization flow, 2.5 gpm/ft²

$A_{EXCHANGER}$ = cross sectional area of the ion exchanger, $\frac{\pi * (5ft)^2}{4} = 19.635 ft^2$

$$Q_{PIPE} = 2.5 gpm / ft^2 * 19.635 ft^2$$
$$Q_{PIPE} = 49.1 gpm \approx 50 gpm$$

A flow rate of 50 gpm will provide an adequate velocity. For cases when the water cannot break up all the resin or it is necessary to limit the volume of sluicing water, air may be injected through the same piping. For the fluidizing water pipe, a throttle valve and flow meter will be used to maintain a constant flow rate. The pressure drop in a 2 in. Schedule 40 pipe, with water flowing at 50 gpm is 2.03 psi/100 ft and the velocity is 4.78 ft/sec (Reference 2.2.24, p. B-14). The length of the resin fluidizing pipe is approximately 45 ft (Attachment 3).

The total pressure drop in the pipe (ΔP_{PIPE}) is calculated:

$$\Delta P_{PIPE} = \frac{2.03 psi}{100 ft} * 45 ft = 0.9135 psi * 2.31 \, {}^{ft}\!/_{psi} = 2.1 ft$$

The fluidizing water will be discharged from the vessel through the top, so the head loss of the water in the ion exchanger must be taken into account. This value is the height of the column which is 8 ft (Section 6.1.9), plus the pressure loss due to the fluidized resin, which is 55% higher than that of just water (Assumption 3.1.30).

$$fluidized\ resin\ pressure\ loss = 8 ft * 1.55 = 12.4 ft$$

This brings the total head loss to 14.5 ft or 6.27 psi.

Because the water is being tapped from the main pool water return pipe before the heat exchanger (near Node 12 on p. 1 of Attachment 1), a pump is not being utilized. This increases the necessity for minimal pressure drop across the pipe. The pressure in the return pipe of the water treatment system is 9.8 psi (22.4 ft); summation of the last three items from Table 9.

$$2.1 psi + 7 psi + 0.7 psi = 9.8 psi$$

This is approximately 60% more than the pressure drop in the fluidization path, so there is sufficient pressure to fluidize the resin in the ion exchanger.

6.2.3 Main Sluicing and Recirculation Pipes

The flow rate of slurry being sluiced from the ion exchanger should match the flow rate of water entering the ion exchanger. The recommended schedule 40 pipe size for a 50 gpm flow rate of slurry is 1.5 in. (Reference 2.2.34, Table V). This volumetric flow rate and pipe size combination prevents the resin from settling in the sluicing pipes (7.88 ft/sec). For this calculation a flow rate of 50 gpm will be used.

The piping from the ion exchanger outlet to the interface with the vendor supplied dewatering system is approximately 145 ft (Assumption 3.1.24). The piping will be run through the concrete floor from the ion exchangers to the transfer pump. It will leave the pump and be routed back into the concrete floor. It will then be routed outside of the west wall of the WHF (Attachment 3). At this point it will run up 10 ft (Assumption 3.1.24) to interface with the vendor supplied dewatering system (Assumption 3.1.25). The recirculation piping will total approximately 156 ft (Assumption 3.1.24). Both the sluicing and recirculation pipes will be Schedule 40 stainless steel pipes (Reference 2.2.43, Attachment 1).

For water flowing at 50 gpm in a 1.5 in. Schedule 40 steel pipe, the pressure drop per 100 ft of straight pipe is found to be 7.15 psi/100 ft (Reference 2.2.24, p. B-14). For the 145 ft of sluicing pipe, the equivalent pipe length including valves and fittings is 290 ft (145 * 2) (Assumption 3.1.6).

$$h_L = 290\,ft * \frac{7.15\,psi}{100\,ft} = 20.7\,psi \qquad \text{(Use 21 psi or 48.5 ft)}$$

The pressure drop of the resin slurry is 55% higher than that for water (Reference 2.2.34, Section 4.3). Because head loss is proportional to pressure drop, the same ratio may be used.

$$h_{Lslurry} = 1.55 \times 48.5\,ft = 75.2\,ft \qquad \text{(Use 76 ft)}$$

6.2.4 Pump Sizing

Using the Bernoulli theorem (Equation 4), the total head for the system can be calculated and used to determine the horsepower of the pump:

$$H = 144\left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}\right) + \left(Z_2 - Z_1\right) + \left(\frac{v_2^2 - v_1^2}{2g}\right) + h_L$$

where

H	=	total head, feet of fluid	
P_2	=	pressure at end of piping system, psia	(atmospheric)
P_1	=	pressure at beginning of piping system, 9.8 psia	(Section 6.2.2)
$\rho_1 = \rho_2$	=	density of borated water, 62.4 lb/ft^3	(Assumption 3.2.1)
Z_2	=	height of pipe discharge, 4 ft	(Assumption 3.1.24)
Z_1	=	height of pipe inlet, -1 ft	(Table 2)
v_2	=	mean velocity at pipe discharge, 7.88 ft/sec	(Reference 2.2.24, p. B-14)
v_1	=	mean velocity at pipe inlet, 4.78 ft/sec	(Reference 2.2.24, p. B-14)
g	=	acceleration due to gravity, 32.2 ft/sec^2	
h_L	=	head loss due to friction, 78.1 ft (76 ft +2.1 ft)	(Sections 6.2.2 and 6.2.3)

For this piping system, the Bernoulli equation simplifies to:

$$H = 144\left(\frac{22.4\,ft}{62.4\,\frac{lb}{ft^3}} - \frac{30.1\,ft}{62.4\,\frac{lb}{ft^3}}\right) + \left(4\,ft - \left(-1\,ft\right)\right) + \left(\frac{\left(7.88\,\frac{ft}{\sec}\right)^2 - \left(4.78\,\frac{ft}{\sec}\right)^2}{2 * 32.2\,\frac{ft}{\sec^2}}\right) + 78.1\,ft = 65.9\,ft \quad (Use\ 66\,ft)$$

The required pump size is found using Equations 3 and 4:

$$Hydraulic\ hp = \frac{8.33Hs(gal/\min)}{33000}$$

$$Hydraulic\ hp = \frac{(8.33 * 66\,ft * 1 * 50\,gal/\min)}{33000} = 0.83hp$$

$$Brake\ hp = \frac{Hydraulic\ hp}{Pump\ efficiency}$$

$$Brake\ hp = \frac{0.83}{0.60} = 1.38hp \qquad (Use\ 2\ hp)$$

The piping for the recirculation path will never be in use while the sluicing pipe is being used. The piping will be valved so that the same transfer pump can be used for both paths. The recirculation path is a closed loop, so the only losses incurred are system friction losses.

$$h_{L,recirculation} = 156\,ft * 2 = 312\,ft * \frac{7.15\,ft}{100\,ft} = 22.3\,ft * 1.55 = 34.6\,ft * \frac{2.31\,psi}{ft} = 80\,ft$$

The required pump size is found using Equations 3 and 4:

$$Hydraulic\ hp = \frac{8.33Hs(gal/\min)}{33000}$$

$$Hydraulic\ hp = \frac{(8.33 * 80\,ft * 1 * 50\,gal/\min)}{33000} = 1.01hp$$

$$Brake\ hp = \frac{Hydraulic\ hp}{Pump\ efficiency}$$

$$Brake\ hp = \frac{1.01}{0.60} = 1.68hp \qquad (Use\ 2\ hp)$$

A 2 hp pump (050-PW00-P-00004A and B) will be sufficient for sluicing and recirculating the resin slurry.

6.2.5 Net Positive Suction Head Available

The pump's $NPSH_A$ is calculated using Equation 5:

$$NPSH_A = h_{sp} \pm h_s - h_f - h_{vp}$$

where

h_{sp} = static pressure head (absolute) applied to the fluid (ft)
h_s = elevation difference
h_f = friction loss in the suction piping (ft)
h_{vp} = vapor pressure of the fluid at the pumping temperature (ft)

The calculation for $NPSH_A$ is:

h_{sp} = 30 ft (Section 6.1.7.4)

h_s = 4.5 ft (Attachment 3, node 6 elevation – node 7 elevation)

h_f = 105 ft (Attachment 3) * 7.15psi/100 ft (Reference 2.2.24, B-14) * 1.55 (add 55% for slurry (Reference 2.2.34, Section 4.3)) = 11.64 psi = 26.88 ft

h_{vp} = 0.42964 psia (Assumption 3.2.8) = (0.42964 psia * 2.31 ft/psia) = 0.992 ft (Use 1.0)

$NPSH_A$ = (30 + 4.5 – 26.88 – 1) = 6.62 ft 6.62/2.31 =2.87 psia

6.2.6 Resin Dewatering Pipe

The dewatering pipe for the spent resin handling system will be the same size as the sluicing line. The slurry will be entering the vendor supplied dewatering system at 50 gpm; therefore the water content of this slurry cannot be pumped out of the receipt vessel at a continuous rate any higher than 50 gpm. Because the friction loss of water is 55% less than that of the resin slurry (Reference 2.2.34, Section 4.3) and a 1.5 in. sluicing pipe is used, a 1.5 in. pipe is sufficient for handling water at and below 50 gpm. The dewatering pipe will be run from the connection within the vendor supplied dewatering system, to a C3 drain inside the WHF.

6.2.7 Pipe Bends and Valves

According to *Nuclear Engineering Design Guide for Spent Resin Handling Systems* (Reference 2.2.34, Section 6.2.1), the minimum recommended bend radius for piping is 5D. The recommended valves used in this system will be plug valves (Reference 2.2.34, 6.3.1).

6.3 POOL WATER COOLING SUBSYSTEM

The pool water cooling subsystem maintains the pool water at a given temperature. The pool temperature is chosen to reduce corrosion of the fuel cladding, reduce evaporation from the pool, and meet the temperature limits identified in the PDC (Reference 2.2.11, Section 4.9.7.5.3). Figure 3 shows a schematic of the heat exchanger flow path.

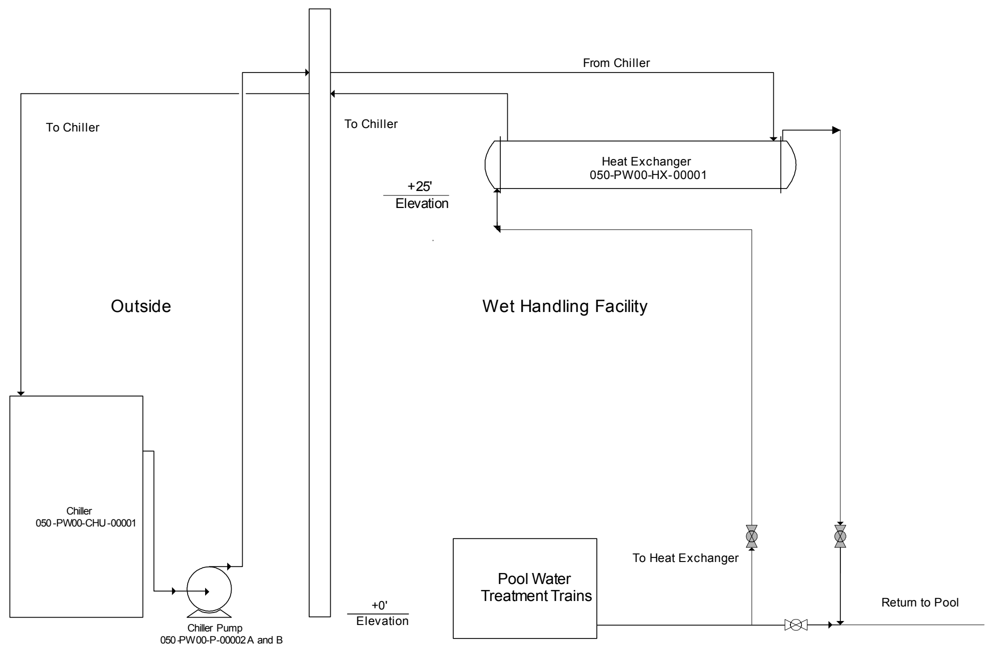


Figure 3. Heat Exchanger Flow Path

Treated water is supplied to the pool water cooling subsystem. The treated water bypasses the cooling subsystem if the pool water is within the acceptable temperature range. The pool water cooling system is sized to remove the maximum possible heat load from SNF in the WHF pool. No credit is taken for heat loss due to evaporation of water from the pool.

The following are addressed in this section:

- Pool temperature monitoring
- Maximum heat load in the WHF pool
- Surface area of heat exchanger
- Pipe sizing
- Heat exchanger sizing and selection
- Commercial chiller sizing
- Chiller pump sizing.

6.3.1 Pool Temperature Monitoring

Because the pool treatment trains may not run continuously (Section 6.1.3), the pool water temperature will need to be monitored from the pool as well as in the treatment train. The pool water temperature will be monitored by two instruments; one instrument located in each of the two pool sections, the DPC unloading bay and the Fuel transfer area. The instruments will be linked to indicators in the central control room.

6.3.2 Heat Load for Pool

The maximum heat load for the WHF pool (Table 10) is calculated based on the pool being fully loaded with fuel, casks, and TAD canisters. The casks, DPCs and TAD canisters with the highest heat load are chosen. A rail transportation cask is included although the WHF is not expected to receive directly-loaded rail transportation casks (Reference 2.2.1, Table 2).

The fuel racks in the pool hold 80 PWR and 120 BWR fuel assemblies (Assumption 3.1.11). Fully loaded, the pool can hold (Assumption 3.1.11):

- One DPC (Reference 2.2.16, Section 1.2.1.3)
- One TAD canister (Reference 2.2.27, Section 3.1.3)
- One truck cask (Reference 2.2.15, Table 1.2.4)
- One rail cask (Reference 2.2.16, Table 1.2-2)
- One TAD canister in remediation (Reference 2.2.27, Section 3.1.3).

Table 10. Maximum Heat Load for Pool

Item in Pool	Count	Power (kW)	Total Power (kW)	Source
BWR Assemblies	120	0.344	41	Assumptions 3.1.11 and 3.1.12
PWR Assemblies	80	1.05	84	Assumptions 3.1.11 and 3.1.12
DPC (NAC-STC)	1	22.1	22.1	Reference 2.2.16, Section 1.2.1.3
Fuel Solutions TS-125 (W74 Transportation Canister)	1	2.5	2.5	Reference 2.2.15, Table 1.2.4
Rail Cask (NAC-STC directly loaded)	1	22.5	22.5	Reference 2.2.16, Table 1.2-2
TAD Canister	1	25	25	Reference 2.2.27, Section 3.1.3
TAD Canister Remediation	1	25	25	Reference 2.2.27, Section 3.1.3
Total			222.1	

$$Heat\ Load = 222.1kW * 3414.43 \frac{Btu/hr}{kW} = 758{,}000\, Btu/hr \qquad \text{(Use 760,000 Btu/hr)}$$

The standard atmospheric pressure used at the site elevation is 13.021 psia, as discussed in Section 6.1.7.3. Through interpolation, it is found that the boiling temperature of water at this pressure is approximately 206 ºF (Reference 2.2.37, p. 402, Table 13.3).

At 48 ft, the total volume of the pool is 1,440,000 gals (Section 6.1.1). Assuming no heat loss due to evaporation, the time it takes to raise the temperature from 75ºF to 206ºF (boiling point) is found as follows:

$$1{,}440{,}000 gal * 8.34\, Btu/gal \cdot F * (206^{o} F - 75^{o} F) * \frac{1hr}{760{,}000 Btu} * \frac{1day}{24hr} = 86.3\ days \text{ (Use 86 days)}$$

Assuming a 30 day outage, the maximum heat load (760,000 Btu/hr), a starting pool temperature of 75ºF, and the minimum evaporative loss (264,000 Btu/hr (Section 6.4.1.1)), the final pool temperature is:

$$30 days * \frac{24 hr}{day} * (760{,}000 - 264{,}000)\frac{Btu}{hr} * \frac{1 gal \cdot °F}{8.34 Btu} * \frac{1}{1{,}440{,}000 gal} + 75°F = 105°F$$

These values are conservative since they are based on the maximum heat load, no heat losses to the surrounding (other than evaporation) and an evaporative loss calculated at the low temperature (75°F). As shown in Section 6.4.1.3, the actual maximum pool water temperature is 102°F. Therefore, pool boiling is not a credible scenario. **Heat Exchanger Surface Area**

The size of the heat exchangers (050-PW00-HX-00001A and B) is based on 350 gpm flow of treated water through the heat exchanger to remove 760,000 Btu/hr. Each heat exchanger will be designed to remove 100% of the maximum pool heat load.

6.3.3.1 Treated Water Temperature Change

The flow rate of treated water to the heat exchanger is either 350 gpm for one treatment train or 700 gpm for two 350 gpm treatment trains. For sizing the heat exchanger to remove the maximum pool heat load, the 350 gpm flow is more conservative. The change in temperature required to remove 760,000 Btu/hr is calculated using the heat capacity of water, Equation 9 (Reference 2.2.28, Equation 15-3). The nomenclature used for this calculation is slightly different from that used in *Heat Transmission* (Reference 2.2.28).

$$\mathrm{Q} = \mathrm{wC_p}(\mathrm{T_2} - \mathrm{T_1}) \qquad \text{(Eq. 9)}$$

where

Q	=	heat load, Btu/hr	
w	=	mass flow rate, lb/hr	
C_p	=	heat capacity of water, 1 Btu/lb-ºF	(Assumption 3.2.3)
T_2	=	temperature of treated water leaving heat exchanger	
T_1	=	temperature of treated water entering heat exchanger, 75°F	(Assumption 3.1.9)

The volumetric flow rate (350 gpm) is converted to mass flow rate by multiplying by the density of the fluid, 62.4 lb/ft^3 for borated water (Assumption 3.2.1):

$$w = 350\frac{gal}{\min} * 62.4\frac{lb}{ft^3} * \frac{ft^3}{7.481 gal} * \frac{60 \min}{hr} = 175{,}000\frac{lb}{hr}$$

Equation 9 is rearranged to calculate the change in temperature:

$$T_2 = \frac{Q}{wC_p} + T_1$$

$$T_2 = \frac{-760{,}000 Btu/hr}{175{,}000 \frac{lb}{hr} * \frac{1Btu}{lb{*}^{o}F}} + 75^{o}F = 70.7^{o}F$$

6.3.3.2 Log Mean Temperature Difference

The log mean temperature difference is used to size the surface area required for the heat exchanger. The WHF pool temperature is 75ºF (Assumption 3.1.9). As calculated above, the temperature of the treated water leaving the heat exchanger is 70.7ºF. The cooling water enters the heat exchanger at 50°F and leaves at 60°F (Assumption 3.1.13). Equation 10 is used to calculate the log mean temperature difference for the heat exchanger (Reference 2.2.5, Equation 10-118b):

$$\Delta T_m = \frac{(T_{pool\ in} - T_{cool\ out}) - (T_{pool\ out} - T_{cool\ in})}{\ln\left(\frac{T_{pool\ in} - T_{cool\ out}}{T_{pool\ out} - T_{cool\ in}}\right)} \qquad \text{(Eq. 10)}$$

where

$T_{cool\ in}$ = 50ºF
$T_{cool\ out}$ = 60ºF
$T_{pool\ in}$ = 75ºF
$T_{pool\ out}$ = 70.8ºF

$$\Delta T_m = \frac{(75^{o}F - 60^{o}F) - (70.8^{o}F - 50^{o}F)}{\ln\left(\frac{75^{o}F - 60^{o}F}{70.8^{o}F - 50^{o}F}\right)} = 17.7^{o}F$$

6.3.3.3 Surface Area

The heat exchanger surface area depends on the amount of heat to be removed and the temperature differential between the cooling liquid and the liquid to be cooled. The heat exchanger will be used intermittently since it is unlikely that the pool will ever be fully loaded. Figure 4 presents a diagram of the pool water and cooling water flow to and from the heat exchanger.

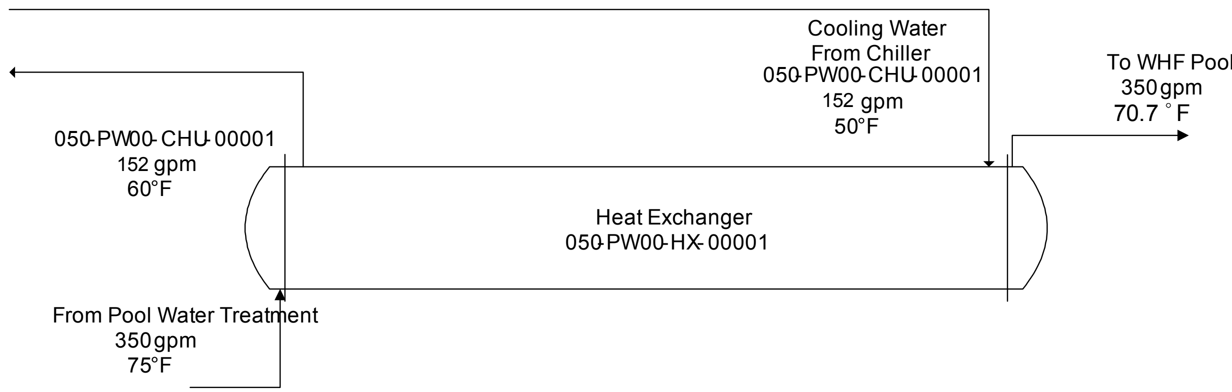


Figure 4. Heat Exchanger Diagram

The outside surface area of the heat exchanger tubes is calculated using Equation 11 (Reference 2.2.5, Equation 10-117):

$$A_o = \frac{Q}{U_{om} * \Delta T_m} \qquad \text{(Eq. 11)}$$

where

A_o	=	outside surface area	
Q	=	heat load, 760,000 Btu/hr	(Section 6.3.1)
U_{om}	=	mean overall heat transfer coefficient, 300 Btu/ºF-ft^2-hr	(Assumption 3.2.2)
ΔT_m	=	log mean temperature difference, 17.7°F	(Section 6.3.2.2)

$$A_o = \frac{760{,}000\ Btu/hr}{300\ \frac{Btu}{^oF * ft^2 * hr} * 17.7^oF} = 143\ ft^2$$

6.3.3.4 Cooling Water Flow Rate

The mass flow rate for the cooling water is a function of the desired temperature changes of these streams in the heat exchanger. The mass flow rates are calculated using the temperature change and the heat capacity of water as shown previously in Equation 9:

$$m = \frac{Q}{C_p \Delta T}$$

$$m = \frac{760{,}000\ \frac{Btu}{hr}}{\left(1\ \frac{Btu}{lb\ ^oF}\right)\left(60^o F - 50^o F\right)} = 76{,}000\ \frac{lb}{hr}$$

The volumetric flow rate is calculated from the mass flow rate by dividing by the density of borated water (Assumption 3.2.1):

$$\nu = \frac{76{,}000\,\dfrac{lb}{hr}}{62.4\,\dfrac{ft^3}{\min}} * \left(\frac{hr}{60\min}\right) * \left(\frac{7.481 gal}{ft^3}\right) = 152\,\frac{gal}{\min}$$

6.3.4 Pipe Size for Cooling Water

The pressure drop and velocity of flow through a pipe is taken from *Flow of Fluids through Valves, Fittings, and Pipe* (Reference 2.2.24, p. B-14). A 3 in. pipe will be used for cooling water. By interpolation, the pressure drop for the cooling water at 152 gpm is 2.30 psi/100 ft of pipe and the velocity is 6.60 ft/sec.

6.3.5 Heat Exchanger Selection

The diameter of the heat exchanger tubes is a tradeoff between surface area for heat transfer and pressure drop through the heat exchanger. Turbulent flow increases the heat transfer rate but also increases the pressure drop through the heat exchanger.

Using the required heat transfer area of 143 ft^2 (Section 6.3.3.3), the number of tubes needed for the heat transfer can be calculated using the outside diameter of tubing. For 1-1/4-in. tubing (Assumption 3.1.14), the outside diameter is 1.25 in. The internal surface area per foot of 1-1/4-in. 14 gauge tubing is 0.2838 ft^2/ft (Reference 2.2.5, Table 11-2).

For a 10 ft long heat exchanger (Assumption 3.1.14), the number of tubes is:

$$Number_{Tubes} = \frac{143\,ft^2}{0.2838\,\dfrac{ft^2}{ft} * 10\,ft} = 50.4\ tubes$$

Using *Chemical Engineers' Handbook* (Reference 2.2.5, Table 11-3H) for 1-1/4 in. tubes on 1-9/16 in. triangular pitch, the nearest size for at least 50.4 tubes is a shell inside diameter of 13-1/4 in. with 55 tubes. The heat exchanger size has been calculated to provide input to the solid model for WHF. The vendor supplying this equipment will establish the actual design and size.

6.3.6 Chiller Selection

Two commercial, air-cooled chillers (050-PW00-CHU-00001 and –00002) are used to provide chilled deionized water for the heat exchangers. The cooling load for the chiller is 222.1 kW (Table 10), 760,000 Btu/hr (Section 6.3.2), or about 64 tons refrigeration. The cooling water will be a closed-loop system that provides cooling water at 50ºF (Assumption 3.1.13). The chiller will be located external to the WHF as shown in Attachment 1.

6.3.7 Cooling Water Pumps

The cooling water pumps (050-PW00-P-00002A and B) provide the cooling water for the chillers to the heat exchangers (050-PW00-HX-00001A and B). The horsepower and $NPSH_A$ are calculated for these pumps. The cooling water piping system will have to be filled from an outside source.

6.3.7.1 Pump Total Head and Horsepower

The cooling water system is a closed-loop piping system of deionized water. Using the Bernoulli equation for non-compressible fluid (Equation 4):

$$H = 144\left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}\right) + \left(Z_2 - Z_1\right) + \left(\frac{v_2^2 - v_1^2}{2g}\right) + h_L$$

where

$P_2 = P_1$	=	pressure at end and beginning of piping system, psi	(closed-loop system)
$\rho_2 = \rho_1$	=	density of deionized water, 62.4 lb/ft^3	(Assumption 3.2.1)
$Z_2 = Z_1$	=	height at end and beginning of piping system, ft	(closed-loop system)
$v_2 = v_1$	=	mean velocity, ft/sec	(closed-loop system)

For this piping system, the Bernoulli equation simplifies to:

$$H = h_L$$

The head losses for cooling water piping are presented in Table 11. The pressure drop through pipe is taken from *Flow of Fluids through Valves, Fittings, and Pipe* (Reference 2.2.24, p. B-14). The length of pipe between equipment and the pressure drops through equipment are based on Assumptions 3.1.5 and 3.1.7. For pipe fittings and valves, the equivalent length of piping is double the piping length (Assumption 3.1.6).

Table 11. Pressure Loss for Cooling Water Piping

Piping and Equipment	Length (ft)	Equivalent Length (ft)	Pressure Drop (psi/100 ft)	Pressure Drop (psi)	Head Loss (ft)	Assumption
3 in. Schedule 40 pipe (152 gpm)	160	320	2.3	7.36	17	Assumption 3.1.5, Section 6.3.4
Heat Exchanger (Shell Side)				5	11.6	Assumption 3.1.7
3 in. Schedule 40 pipe (152 gpm)	160	320	2.3	7.36	17	Assumption 3.1.5, Section 6.3.4
Chiller				10	23.1	Assumption 3.1.7
Total				29.7	68.7	

Therefore

$$H = h_L = 68.7\,ft = 29.7\,psi \quad \text{(Use 30 psi)}$$

To minimize the potential for pool water to enter the cooling water loop in the event of a leak/failure of the heat exchanger tubes, the shell side pressure should be kept at a higher pressure than the tube side pressure. To accomplish this, the cooling water pump discharge pressure is set equal to 130 psi (the pool water treatment pump discharge pressure or 100 psi (Section 6.1.7.2) plus the cooling system head loss or 30 psi).

The specific gravity of deionized water is 1.0 (Assumption 3.2.1). The mass flow rate of the pool water treatment subsystem is calculated from the volumetric flow rate of 152 gpm by multiplying by the density of water. The hydraulic horsepower for the pump is calculated using the total dynamic head, the specific gravity of the liquid being pumped, and the flow rate of liquid as shown in Equation 2:

$$Hydraulic\,hp = \frac{(8.33 * 300\,ft * 1 * 152\,gal/\min)}{33{,}000} = 11.5\,hp$$

The pump efficiency is 60% (Assumption 3.1.3). Rearranging Equation 3, the brake horsepower of the pump is calculated by dividing the hydraulic horsepower of the pump by the pump efficiency:

$$Brake\,hp = \frac{11.5\,hp}{60\%} = 19.2\,hp \qquad \text{(Use 20 hp)}$$

6.3.7.2 Net Positive Suction Head Available

The $NPSH_A$ is calculated using Equation 5:

$$NPSH_A = h_a - h_{vpa} \pm h_{st} - h_{fs}$$

$$h_a = 30\,ft \qquad \text{(Section 6.1.7.3)}$$

The saturated vapor pressure of water at 50°F (Assumption 3.1.13) is 0.17796 psi (Reference 2.2.20, p. E-23). This is converted to feet of water by dividing by the density of water.

$$h_{vap} = \frac{0.17796\,\frac{lb}{in^2}}{62.4\,\frac{lb}{ft^3}} * \left(\frac{12\,in}{ft}\right)^2 = 0.4\,ft$$

The static head is 0 ft because this is a closed-loop system. The head loss in the suction piping is negligible because the pump will be located in close proximity to the chiller. Therefore, h_{fs} is 0 ft.

Thus, the $NPSH_A$ is:

$$NPSH_A = 30\,ft - 0.4\,ft + 0\,ft - 0\,ft = 29.6\,ft \qquad \text{(Use 30 ft)}$$

6.4 POOL WATER LEVEL CONTROL AND MAKEUP SUBSYSTEM

The deionized water system supplies the makeup water for the WHF pool as identified in the PDC (Reference 2.2.11, Section 4.9.7.5.4). The water level in the pool is maintained above a minimum level to ensure shielding of the spent fuel assemblies. Deionized makeup water is added as the pool level drops to compensate for evaporation.

The following are addressed in this section:

- Minimum evaporation rate from WHF pool
- Maximum evaporation rate from WHF pool
- Displacement of WHF pool water by casks
- Makeup water flow rate
- Pipe sizing
- Pool level monitoring instrumentation
- Alert and alarm pool levels.

6.4.1 Water Loss by Evaporation

The ambient temperature and humidity of the air in the WHF, as well as the flow rate of air across the surface of the pool, affect the water loss by evaporation.

The evaporation rate of water can be estimated by an empirical correlation developed for evaporation rate from indoor swimming pools as shown in Equation 12 (Reference 2.2.28, p. 4.7):

$$w_p = A(p_w - p_a)(95 + 0.425V)/Y \qquad \text{(Eq. 12)}$$

where

w_p = evaporation rate of water, lb/hr
A = area of pool surface, (61 ft)*(75 ft) = 4,575 ft^2 (Figure 1)
p_w = saturation vapor pressure taken at the surface water temperature, in. Hg
p_a = saturation pressure at room air dew point, in. Hg
V = air velocity over water surface, fpm
Y = heat of vaporization, Btu/lb

The air velocity over the water surface is calculated using a turnover rate of 1.2 air changes per hour (Assumption 3.1.15). The length of the WHF pool room is 200 ft (Reference 2.2.2). Therefore, the air velocity is:

$$V = \frac{200\,ft * 1.2}{60\,\text{min}} = 4.0\, {}^{ft}\!/_{\text{min}}$$

The heat of vaporization *(Y)* and the saturation vapor pressure *(p_w)* depend on the temperature of the pool water. At 75ºF (Assumption 3.1.9):

p_w = 0.42964 psia*(2.03602 in. Hg/psi) = 0.87476 in. Hg (Reference 2.2.20, p. E-23)
Y = 1051.2 Btu/lb (Reference 2.2.20, p. E-23)

6.4.1.1 Minimum Evaporation at Normal Pool Temperature

The indoor dew point temperature is 43ºF (Assumption 3.1.16) during cooling. This results in the minimum evaporation rate for 75°F pool water. The vapor pressure for water at 43ºF is:

p_a = 0.13659 psia*(2.03602 in. Hg/psi) = 0.2781 in. Hg (Reference 2.2.20, p. E-23)

Therefore, using Equation 12:

$$w_p = 4575*(0.87476-0.2781)*(95+0.425*4.0)/1051.2 = 251 lb/hr$$

$$Volume = 251\frac{lb}{hr}*\frac{ft^3}{62.4lb}*\frac{7.481gal}{ft^3} = 30.1\frac{gal}{hr} \quad \text{(Use 30 gal/hr)}$$

The heat loss from the pool due to evaporation for the minimum evaporation case is:

$$Q = 251\frac{lb}{hr}*1051.2\frac{Btu}{lb} = 263{,}851\frac{Btu}{hr} \quad \text{(Use 264,000 Btu/hr)}$$

6.4.1.2 Maximum Evaporation at Normal Pool Temperature

The maximum evaporation rate of water occurs when the vapor pressure of the air is 0 in. Hg (Assumption 3.2.4). Therefore, the maximum evaporation rate of 75°F pool water using Equation 12 is:

$$w_p = 4575*(0.87476-0)*(95+0.425*4)/1051.2 = 368 lb/hr$$

$$Volume = 368\frac{lb}{hr}*\frac{ft^3}{62.4lb}*\frac{7.481gal}{ft^3} = 44.1\frac{gal}{hr} \quad \text{(Use 44 gal/hr)}$$

The heat loss from the pool due to evaporation for the maximum evaporation case is:

$$Q = 368\frac{lb}{hr}*1051.2\frac{Btu}{lb} = 387{,}000\frac{Btu}{hr}$$

6.4.1.3 Maximum Pool Temperature

The maximum pool temperature is the point where the evaporative losses equal the heat load in the pool. This can be calculated by solving Equation 12 for p_w and using the steam tables to get the temperature based on p_w. Therefore:

$$w_p = \frac{A(p_w - p_a)(95 + 0.425V)}{Y}$$

$$Q = w_p Y = A(p_w - p_a)(95 + 0.425V)$$

$$p_w = \frac{Q}{[A(95 + 0.425V)]} + p_a$$

where

Q	=	heat load from spent fuel, 760,000 Btu/hr	(Section 6.3.2)
A	=	area of pool surface, (61 ft)*(75 ft) = 4,575 ft^2	(Figure 1)
p_w	=	saturation vapor pressure taken at the surface water temperature, in. Hg	
p_a	=	saturation pressure at room air dew point, 0.2781 in. Hg	(Section 6.4.1.1)
V	=	air velocity over water surface, 4.0 fpm	(Section 6.4.1)

The value for p_a is based on the minimum evaporation rate since this provides the highest final pool temperature.

$$p_w = \frac{760{,}000\,{}^{Btu}\!/_{hr}}{4575\,ft^2\left(95 + 0.452 * 4.0\,{}^{ft}\!/_{\min}\right)} + 0.2781 in.\,Hg = 1.994 in.\,Hg = 0.98 psia \quad \text{(Use 1.0 psia)}$$

From the steam tables (Reference 2.2.24, p. A-12), a vapor pressure of 1.0 psia corresponds to a temperature of approximately 102°F.

6.4.1.4 Loss of Make-up Water

To reach the minimum shielding level (35 ft), the pool would need to lose 13 ft of pool water. This 13 ft is equivalent to approximately 446,000 gals (2860 gals/in - Section 6.4.9). The minimum and maximum evaporative losses for the pool are 30 gal/hr and 44 gal/hr respectively, (Sections 6.4.1.1 and 6.4.1.2) based on a pool temperature of 75ºF. At the maximum rate, the time it would take to evaporate enough water to reach the 35 ft level is:

$$\frac{hr}{44 gal} * 446{,}000 gal * \frac{1 day}{24 hr} = 422.3\ days \qquad \text{(Use 422 days)}$$

At the minimum rate, the duration is 619 days.

Assuming the maximum heat load (Section 6.3.2), the maximum evaporation rate (Section 6.4.1.2), and a pool temperature of approximately 102ºF (Section 6.4.1.3), the evaporation rate is found as follows:

The vapor pressure of water at approximately 102ºF is 1.0 psia (Section 6.4.1.3) or 2.036 in. Hg. Therefore, using Equation 12:

$$w_p = 4575 * (2.036 - 0) * \frac{(95 + 0.425 * 4)}{1051.2} = 857 \frac{lb}{hr}$$

$$Volume = 857 \frac{lb}{hr} * \frac{ft^3}{62.4 lb} * \frac{7.481 gal}{ft^3} = 103 \frac{gal}{hr}$$

Assuming a 30 day outage results in a loss of

$$Volume = 103 \frac{gal}{hr} * 24 \frac{hr}{day} * 30 days = 74160 gal$$

$$Height = 74160 gal * \frac{1 in.}{2860 gal} = 25.93 in. \approx 2.25 ft$$

To lose the entire 446,000 gal at 103 gal/hr, the outage would need to last 180 days.

6.4.2 Legal-Weight Truck Cask Displacement

For LWT casks, the volume and displacement (Table 12) in the WHF pool are calculated using the equation for a right cylinder (Equation 6) (Assumption 3.2.5).

$$Volume = Length * \frac{\pi}{4} * Diameter^2$$

Table 12. Displacement for Legal-Weight Truck Casks

LWT Cask	Length (in.)	Diameter (in.)	Volume (in.^{3})	Volume (ft^3)	Reference
NAC-LWT	199.8	44.24	307,172	178	Reference 2.2.15, Section 1.2.1.2.1
GA-4	187.76	46.25	315,440	183	Reference 2.2.13, Section 1.2.1.1
GA-9	198.3	46.68	339,371	196	Reference 2.2.14, Section 1.2.1.1

The GA-9 cask has the largest volume and is used to calculate the displacement of water in the WHF pool for LWTs.

$$Displacement_{STC} = \frac{Volume_{STC}}{Pool\ Surface\ Area} = \frac{196 ft^3}{4575 ft^2} = 0.0428 ft = 0.514 in \qquad \text{(Use 0.6 in.)}$$

6.4.3 Site Transfer Cask Displacement

Both TAD canisters and DPCs will be placed in a STC for shielding before being placed in the WHF pool. The STCs are assumed to be right cylinders 22 ft high and 9 ft in diameter (Assumption 3.2.7). The maximum displacement of water in the pool can be calculated using Equation 6:

$$Volume_{STC} = \frac{L\pi D^2}{4} = \frac{22\,ft * 3.1416 * (9\,ft)^2}{4} = 1400\,ft^3$$

$$Displacement_{STC} = \frac{Volume_{STC}}{Pool\ Surface\ Area} = \frac{1400\,ft^3}{4575\,ft^2} = 0.31\,ft = 3.7\,in \quad \text{(Use 4.0 in.)}$$

6.4.4 Decontamination Water Accumulation

Deionized water will be used to rinse the casks removed from the pool to wash off contaminated water. The casks will be sprayed while suspended over the pool. The rinse water will fall into the pool. It is assumed that the amount of deionized water needed to rinse the casks is less than the minimum evaporation rate for the WHF pool (Assumption 3.1.18).

6.4.5 Deionized Water Supply

When the Lo-Level alarm is reached, pool filling is initiated until the Hi-Level is reached (Section 6.4.9). This is a 6 in. change in the pool water level. The volume of water required is:

$$Makeup = 6in * \left(\frac{2858gal}{in}\right)(Section\ 6.4.9) = 17{,}148gal \quad \text{(Use 17,200 gal)}$$

6.4.6 Makeup Flow Time

The flow rate for the makeup water is 200 gpm (Assumption 3.1.17). The time it takes to fill the pool from the Lo-Level to the Hi-Level is found below.

$$Makeup\,Time = \frac{17200\,gal}{200\,{gal}/{\min}} * \frac{hr}{60\min} = 1.43hr \qquad \text{(Use 1.5 hr)}$$

6.4.7 Pipe Sizes

Pressure drop through pipe is taken from *Flow of Fluids through Valves, Fittings, and Pipe* (Reference 2.2.24, p. B-14).

Table 13 presents the pressure drop for 3 in. and 4 in. Schedule 40 pipe at 200 gpm.

Table 13. Relative Pressure Drops for Makeup Water Piping

Flow Rate (gpm)	Pipe Diameter Sch. 40	Pressure Drop (psi/100 ft pipe)	Velocity (ft/sec)
200	4 in.	0.985	5.04
	3 in.	3.87	8.68

The makeup water pipe should be 4 in. Schedule 40 pipe.

6.4.8 Borated Water Makeup

Borated water will be used to sluice spent resin from the ion exchangers. This water will not be returned to the pool. Due to this, deionized water will be added to the pool to raise the water level and consequently, the concentration of boric acid in the pool will decrease. The change in concentration is not expected to be significant. To account for this decrease, a borated water make up system will supply the pool with a boric acid solution (Reference 2.2.35). This system will pump borated water into the pool water treatment and cooling system at the pool supply pipe (Assumption 3.1.27).

6.4.9 Level Monitoring Instrumentation

The normal pool level is 48 ft (Assumption 3.1.2). The water level of the pool at any given point during operation will vary mainly due to immersion and removal of casks and evaporation of water. These fluctuations are unavoidable and must be allowed to a certain extent. A commercially available sonic/radar level transmitter will be used to monitor the pool level and provide alerts when critical levels are reached (Assumption 3.1.22). Figure 5 shows the various levels of interest such as top of pool, shielding-line, and alarm levels. There will be four levels of concern. The Hi-Level and Lo-Level points bound the operating level of the pool. When the Lo-Level alarm is reached, pool filling is initiated until the Hi-Level is reached. The High Hi-Level and the Low Lo-Level will cause an alarm if reached.

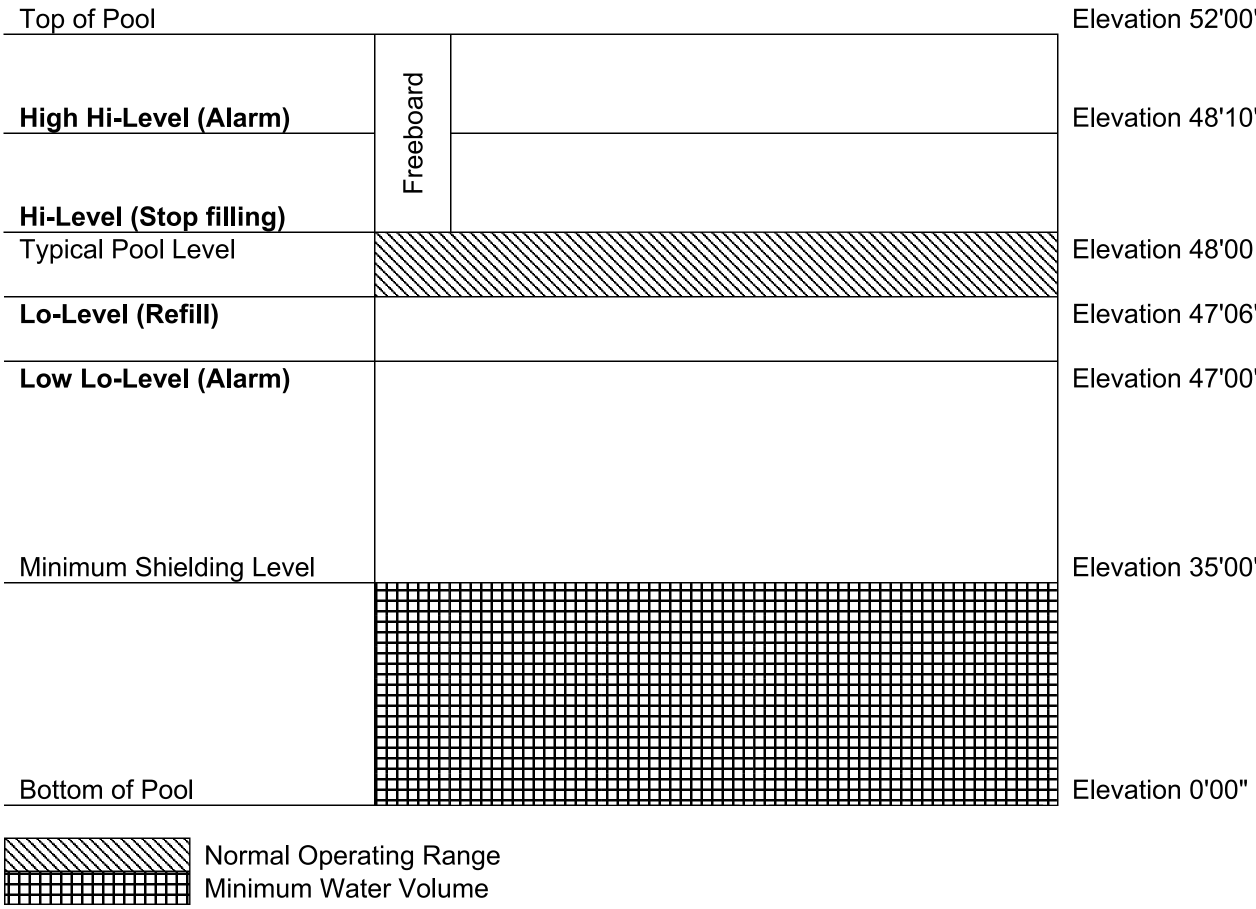


Figure 5. Pool Levels

After processing of the canister is complete, the cask is removed from the pool and the original increase of 4 in. of pool water will be lost as well as loss of pool water from evaporation. If the pool water level drops to or below 47 ft 6 in. (Lo-Level), the deionized water makeup system will automatically begin refilling the pool. This Lo-Level value allows for some loss due to evaporation, reducing the running time of the pool water makeup system, while maintaining sufficient depth to the Low Lo-Level.

A minimum pool level must be maintained for purposes of shielding the SNF. A Low Lo-Level will be instated to prevent depletion of water to the point of affecting the shielding capabilities of the pool. To allow ample time for correction of errors resulting in unacceptably low pool levels, a Low Lo-Level value of 47 ft is chosen. Should the pool water reach this level, an alarm will sound. Makeup of pool water for a level lower than this would become significantly more taxing. The volume of water needed to change the pool water level 1 in. *(V_{water})* is found as follows:

$$V_{water} = A_{surface,\ pool} * 1in = (75ft * 61ft)\frac{1}{12}ft = 382ft^3 = 2858gal$$

Therefore to go from the normal level of 48 ft to the Lo-Level of 47 ft requires a loss of nearly 34,300 gals. The minimum pool level that must be maintained for shielding is 10 ft 6 in. above the fuel (Reference 2.2.32, Section 5.4.3, p. 45). A conservative estimate for the minimum pool level is 35 ft (Assumption 3.1.23). This is well below the Low Lo-Level of 47 ft.

There will be a High Hi-Level alarm. This alarm will operate in the same manner as the Low Lo-Level alarm. It will indicate a malfunction resulting in the pool filling too full. To allow ample time for correction of errors resulting in unusually high pool levels, a High Hi-Level value of 48 ft 10 in. is chosen. This allows for 28,600 gals more than at the normal level of 48 ft.

The typical pool level of 48 ft will provide adequate shielding for most fuel assemblies. During fuel transfers of fuel assemblies longer than 12 ft 6 in., the 10 ft 6 in. shielding height required to keep exposure below 0.25 mrem/hr may be exceeded (Reference 2.2.32, Section 5.4.3, p. 45). These fuel transfers will be preformed infrequently. According to the PDC (Reference 2.2.11, Section 4.10.1.3, Table 4.10.1-1), dose rates for operating galleries, support rooms, and offices at personnel level shall be no more than 0.25 mrem/hr, based on 2,000 hrs occupancy per year. However, it is also stated that higher dose rates may be accepted for transient radiation fields (i.e. source movement) and for lower occupancy areas so long as the yearly dose limit (500 mrem/yr) is not exceeded. Administrative operating procedures will be instated to keep worker doses at an acceptable as low as is reasonably achievable level.

6.5 LEAK DETECTION SUBSYSTEM

The leak detection subsystem is designed in accordance with ANSI/ANS-57.7-1988 (Reference 2.2.10, Section 6.1.4). Leakage from the pool liner is routed to one of two sumps located below the pool bottom. The following items are addressed in this section:

- Maximum leak rate
- Pipe sizing
- Sump pump sizing.

The WHF pool will be constructed of reinforced concrete. The interior portion of the concrete will be coated with a water-impervious sealant. A welded stainless steel liner will be installed in the pool to provide the primary containment of water. The concrete structure supporting the steel pool liner will be equipped with vertical and horizontal chases to route any leakage from the liner to two sumps located below the pool bottom. The sumps are not expected to collect any leakage. Based on *Storage of Water Reactor Spent Fuel in Water Pools, Survey of World Experience* (Reference 2.2.21, Section 7.2.1), spent fuel pools consisting of stainless steel liners in a concrete basin have rarely sustained leaks, and any damage has been minor. The design requirements of ANSI/ANS-57.7-1988 (Reference 2.2.10, Sections 6.1.2.2 and 6.1.2.3) requires that the pool be able to withstand, without loss of functional integrity, the impact of the maximum load over the pool, dropped into the pool from the highest position attainable by the load. Although pool leakage is unlikely, a leakage flow rate of 15 gpm (Assumption 3.2.6) is used to size the pump and piping for returning water to the pool.

Figure 6 shows the proposed layout for the leak detection subsystem.

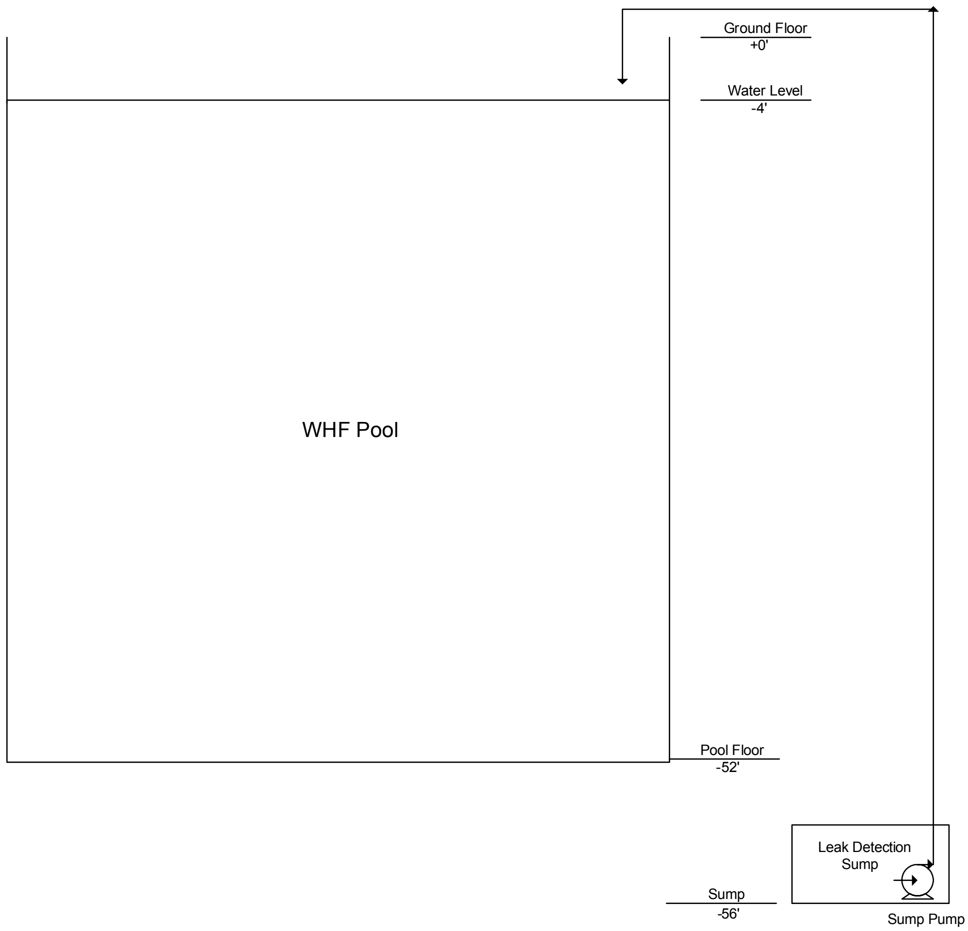


Figure 6. Leak Detection Piping

6.5.1 Leak Detection Sumps

The sizes of the two leak detection sumps in the WHF pool basement (Assumption 3.1.4) have not yet been determined so the volume of the sumps cannot be calculated. One will be located on the north side of the WHF pool and the other on the south side. Leak detection tubes from various areas around the pool will protrude from the sump wall(s). Each of the leak detection tubes is labeled to indicate the region of the pool that is leaking. The sump has instrumentation to detect water in the sump and monitor the leakage rate. Water collected in the sump will be pumped out and returned to the pool.

6.5.2 Pipe Size

A 1-1/2 in. Schedule 40 pipe is chosen since; for a flow rate of 15 gpm (Assumption 3.2.6), the pressure drop through the pipe is 0.755 psi per 100 ft and the velocity is 2.37 ft/sec (Reference 2.2.24, B-14).

6.5.3 Sump Pumps

The sump pumps (050-PW00-P-00003A and B) return any pool water that has leaked through the pool liner, from the leak detection sumps to the WHF pool. The pumps are submerged in the leak detection sumps. The horsepower and $NPSH_A$ are calculated for these pumps.

6.5.3.1 Pump Total Head and Horsepower

Using the Bernoulli theorem (Equation 4), the total head for the system can be calculated and used to determine the horsepower of the pump. The piping system starts at the bottom of the leak detection sump and ends at the top of the WHF pool.

$$H = 144\left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}\right) + \left(Z_2 - Z_1\right) + \left(\frac{v_2^2 - \upsilon_1^2}{2g}\right) + h_L$$

where

H	=	total head, feet of fluid	
P_2	=	pressure at discharge to pool, psi	(atmospheric pressure)
P_1	=	pressure at sump, psi	(atmospheric pressure)
$\rho_1 = \rho_2$	=	density of borated water, 62.4 lb/ft^3	(Assumption 3.2.1)
Z_2	=	height of WHF pool, 0 ft	(Assumption 3.1.4)
Z_1	=	height of sump, −56 ft	(Assumption 3.1.4)
v_2	=	mean velocity at 15 gpm, 2.37 ft/sec	(Reference 2.2.23, B-14)
v_1	=	mean velocity at sump, 0 ft/sec	(stagnant at sump)
g	=	acceleration due to gravity, 32.2 ft/sec^2	
h_L	=	head loss due to friction, feet of fluid	

For this piping system, the Bernoulli equation simplifies to:

$$H = \left(-Z_1\right) + \left(\frac{v_2^2}{2g}\right) + h_L$$

Table 14 presents the pressure loss through the discharge piping. For pipe fittings and valves, the equivalent length of piping is double the piping length (Assumption 3.1.6).

Table 14. Pressure Loss for Leak Detection Water

Piping and Equipment	Length (ft)	Equivalent Length (ft)	Pressure Drop (psi/100 ft)	Pressure Drop (psi)	Head Loss (ft)	Assumption
1-1/2 in. Schedule 40 pipe (15 gpm)	100	200	0.755	1.51	3.5	Assumption 3.1.19 Section 6.5.2

Therefore, the total head is:

$$H = (0-(-56)) + \left(\frac{2.37^2}{64.4}\right) + 3.5 = 59.6\,ft \quad \text{(Use 60 ft or 26 psi)}$$

The hydraulic horsepower is calculated using Equation 2 with a flow rate of 15 gpm:

$$Hydraulic\,hp = \frac{(8.33 * 60\,ft * 1 * 15\,gal/\min)}{33{,}000} = 0.227\,hp$$

Using Equation 3, the brake horsepower of the pump is calculated by dividing the hydraulic horsepower of the pump by the pump efficiency. The pump efficiency is 60% (Assumption 3.1.3).

$$Brake\,hp = \frac{0.227\,hp}{60\%} = 0.38\,hp \qquad \text{(Use 0.50 hp)}$$

6.5.3.2 Net Positive Suction Head Available

The $NPSH_A$ is calculated using Equation 5.

$$NPSH_A = h_a - h_{vpa} \pm h_{st} - h_{fs}$$

$$h_a = 30\,ft \qquad \text{(Section 6.1.7.3)}$$

The saturated vapor pressure of water at 75°F (Assumption 3.1.9) is 0.42964 psi (Reference 2.2.20, p. E-23). This is converted to feet of water by dividing by the density of water.

$$h_{vap} = \frac{0.42964\,\frac{lb}{in^2}}{62.4\,\frac{lb}{ft^3}} * \left(\frac{12in}{ft}\right)^2 = 0.96\,ft \quad \text{(Use 1 ft)}$$

The static head and suction head loss are negligible since the pump is in the sump.

Thus, the $NPSH_A$ is:

$$NPSH_A = 30\,ft - 1\,ft = 29\,ft$$

6.6 POOL CLEANING EQUIPMENT

Some of the crud released from the SNF will sink to the bottom of the pool instead of being removed by the treatment trains. Periodically, the bottom and sides of the pool will be cleaned to remove these particles. Five underwater vacuum units (050-PW00-SKD-00002A, B, C, D, and E) will be placed around the WHF pool to facilitate cleaning the entire pool. These underwater vacuums operate at 260 gpm (Assumption 3.1.20). The filters used in these units are the same size as those used for the 600 gpm underwater filter units. The filters for the underwater vacuum units will filter down to 0.1 micron (Assumption 3.1.7) and have pressure drops of 30 psi (69.3 ft) (Assumption 3.1.7). Special attachments are used with a flexible hose to reach corners and cover large surfaces.

The pump size for the underwater vacuums is found using Equations 2 and 3:

$$Hydraulic\,hp = \frac{8.33 * 69.3 * 1 * 260}{33{,}000} = 4.55hp$$

$$Brake\,hp = \frac{4.55hp}{60\%} = 7.58hp \quad \text{(Use 10 hp)}$$

A 100 gpm floating skimmer (050-PW00-SKR-00001) can be attached to any of the underwater vacuum units by a flexible hose (Assumption 3.1.21). The skimmer is designed to pull water from the surface of the pool through the vacuum unit removing any floating debris from the pool.

7. RESULTS AND CONCLUSIONS

The results of this calculation demonstrate that the design requirements have been met, equipment and piping have been sized, and major components of the pool water treatment and cooling system have been identified. Descriptions and sizing of the equipment will be used by BSC Plant Design as part of the development of the solid model for the WHF. The results of this calculation also provide input for the development of deionized water system piping and instrumentation diagrams.

7.1 POOL WATER TREATMENT SUBSYSTEM

- The volume of the WHF pool is 1,440,000 gal (Section 6.1.1)

- With a pool water treatment train operating at 350 gpm, the turnover rate for the entire WHF pool is less than 72 hr (Section 6.1.2.1).

- With a pool water treatment train operating at 350 gpm and an underwater filter system operating at 600 gpm, the turnover rate for the fuel transfer and fuel staging area of the WHF pool is less than 24 hr (Section 6.1.2.2).

- Two, 600 gpm underwater filters (050-PW00-SKD-00001A, B, C, and D) are placed in both the DPC unloading bay and the fuel transfer area. In each area, one underwater filter unit is operating while the second undergoes filter replacement. Each underwater filter will require a 15 hp motor and have a 2 micron rating (Section 6.1.4).

- The pipes used for supply and return of pool water from the WHF pool, one from the DPC unloading bay and the other from the fuel transfer and fuel staging area, to the pool water treatment trains are 6 in. Schedule 40 (Section 6.1.5).

- The piping used for the pool water treatment trains is 4 in. Schedule 40 (Section 6.1.5).

- In-line strainers (050-PW00-STR-00001A, B, and C) with a pressure drop of 1 psi are used to remove particulates that could harm the pumps (Section 6.1.6). The strainers are sized for a rated flow of 350 gpm.

- The pumps (050-PW00-P-00001A, B, and C) for the pool water treatment trains should be 40 hp for a flow rate of 350 gpm and 100 psi or 230 ft of TDH (Sections 6.1.2.1, 6.1.7.2, and 6.1.7.3).

- The $NPSH_A$ for the pool water treatment pumps is 15 ft (Section 6.1.7.4).

- For each treatment train, two roughing filters (050-PW00-FLT-00001A, 050-PW00-FLT-00003A, 050-PW00-FLT-00005B, 050-PW00-FLT-00007B, 050-PW00-FLT-00009C, and 050-PW00-FLT-00011C) and two polishing filters (050-PW00-FLT-00002A, 050-PW00-FLT-00004A, 050-PW00-FLT-00006B, 050-PW00-FLT-00008B, 050-PW00-FLT-00010C, and 050-PW00-FLT-00012C) with flow rates of 175 gpm are used to remove crud down to 0.1-micron particles. The pressure drops through the roughing and polishing filters are 25 psi and 30 psi, respectively (Section 6.1.8). The ratings for the roughing and polishing filters are 2 micron and 0.1 micron, respectively (Section 6.1.8). All the roughing and polishing filters are 40 in. long and 6 in. in diameter (Section 6.1.8).

- The ion exchange vessels (050-PW00-IX-00001A, B, and C) are 5 ft in diameter and 8 ft high with a bed volume of 50 ft^3 and are sized for a rated flow of 350 gpm (Section 6.1.9). The pressure drop through the ion exchangers is 15 psi (Assumption 3.1.7).

- Resin strainers (050-PW00-STR-00002A, B, and C) with a pressure drop of 1 psi are used to remove smaller, broken or misshapen ion exchange beads that can slip through the screening at the bottom of each ion exchange vessel that might enter the WHF pool (Section 6.1.10). The strainers are sized for a rated flow of 350 gpm.

7.2 SPENT RESIN HANDLING

- Spent resin fluidizing pipe will be 2 in. (Section 6.2.2).

- Spent resin sluicing pipe will be 1.5 in. (Section 6.2.3).

- Spent resin dewatering pipe will be 1.5 in. (Section 6.2.6).

- The spent resin transfer pumps will be 2 hp pumps with a 65 ft head, rated for a flow of 50 gpm (Section 6.2.4).

- All valves in the sluicing pipeline will be plug valves, and all bends will be 5D radius bends to help reduce the number of resin traps in the pipeline (Section 6.2.7).

- The $NPSH_A$ for the spent resin transfer pumps is 4.62 ft (Section 6.2.5).

7.3 POOL WATER COOLING SUBSYSTEM

- The maximum heat load for the WHF pool is 222.1 kW or 760,000 Btu/hr. This does not include any heat loss from evaporation of pool water (Section 6.3.1).

- A 30 day outage with the maximum heat load, a starting pool temperature of 75°F, and the minimum evaporation loss, the final pool temperature is conservatively calculated to be 105 °F (Section 6.3.2). However, the maximum possible pool temperature is 102°F (Section 6.4.1.3).

- The surface area for the shell-and-tube heat exchangers is 143 ft^2 (Section 6.3.3.3).

- The cooling water flow rate to the heat exchangers is 152 gpm (Section 6.3.3.4).

- The pipe size for the cooling water supply and return lines is 3 in. Schedule 40 for a flow rate of 152 gpm (Section 6.3.4).

- The pipe size for the treated water supply and return lines is 6 in. Schedule 40 for a flow rate of 700 gpm, the combined flow rate of two treatment trains (Section 6.1.5).

- The shell-and-tube heat exchangers (050-PW00-HX-00001A and B) will contain 55 1¼ in. tubes and will be 10 ft long with diameters of 13-1/4 in. (Section 6.3.5).

- The commercial chillers (050-PW00-CHU-00001A and B) need to provide a cooling load of 760,000 Btu/hr (64 tons or 222.1 kW) (Section 6.3.6).

- The cooling water pumps (050-PW00-P-00002A and B) are sized for a rated flow of 152 gpm at 130 psi (300 ft) with a 20 hp motor (Section 6.3.7.1).

- The $NPSH_A$ for the cooling water pumps is 30 ft (Section 6.3.7.2).

7.4 POOL WATER LEVEL CONTROL AND MAKEUP

- The minimum evaporation rate for the WHF pool is 30 gal/hr, which results in a heat loss to the pool of 264,000 Btu/hr (Section 6.4.1.1).

The maximum evaporation rate for the WHF pool is 44 gal/hr, which results in a heat loss to the pool of 387,000 Btu/hr (Section 6.4.1.2).The maximum pool temperature is approximately 102°F (Section 6.4.1.3).

- At the maximum evaporation rate, it would take 422 days to evaporate enough water to reach the 35 ft minimum shielding level. When considering the minimum evaporation rate, the duration is 619 days (Section 6.4.1.4).

- Assuming the maximum heat load, the maximum evaporation rate, and a pool temperature of approximately 102°F, the evaporation rate is 103 gal/hr. Assuming a 30 day outage at these conditions, there would be a loss of 74,160 gal of pool water or approximately 2.25 ft. To reach the minimum shielding level under these conditions, it would take a 180 day outage (Section 6.4.1.4).

- Placement of a LWT in the WHF pool results in a rise of 0.6 in. of pool water (Section 6.4.2).

- Placement of an STC containing a DPC or TAD canister into the WHF pool results in a rise of 4 in. of pool water (Section 6.4.3).

- The deionized water used to rinse casks removed from the pool will be less than the minimum evaporation loss of the WHF pool (Assumption 3.1.18).

- To fill the pool from the Lo-Level to the Hi-Level requires 17,200 gal (Section 6.4.5). The deionized water flow rate is 200 gpm to replace the 17,200 gal of pool water in 1.5 hr (Section 6.4.6).

- The pipe size for the deionized water supply is 4 in. Schedule 40 (Section 6.4.7).

- The pool level monitoring instrumentation will be a commercially available radar/sonic level transmitter, mounted above the pool water (Section 6.4.9).

- The alert and alarm levels will be as follows (Section 6.4.9):

High Hi-Level	Alarm	48 ft 10 in.
Hi-Level	Stop Filling	48 ft 0 in.
Lo-Level	Start Filling	47 ft 6 in.
Low Lo-Level	Alarm	47 ft 0 in.

7.5 LEAK DETECTION SYSTEM

- The leak detection system is sized to handle 15 gpm (Assumption 3.2.6).

- There are two leak detection sumps for the WHF pool: one on the north side and the other on the south (Section 6.5.1).

- A 1-1/2 in., Schedule 40 pipe is selected for the sump pump discharge piping (Section 6.5.2).

- The sump pumps (050-PW00-P-00003A and B) are located in the leak detection sumps and are sized for a rated flow of 15 gpm and a total head of 60 ft or 26 psi with a 0.5 hp motor. (Section 6.5.3.1)

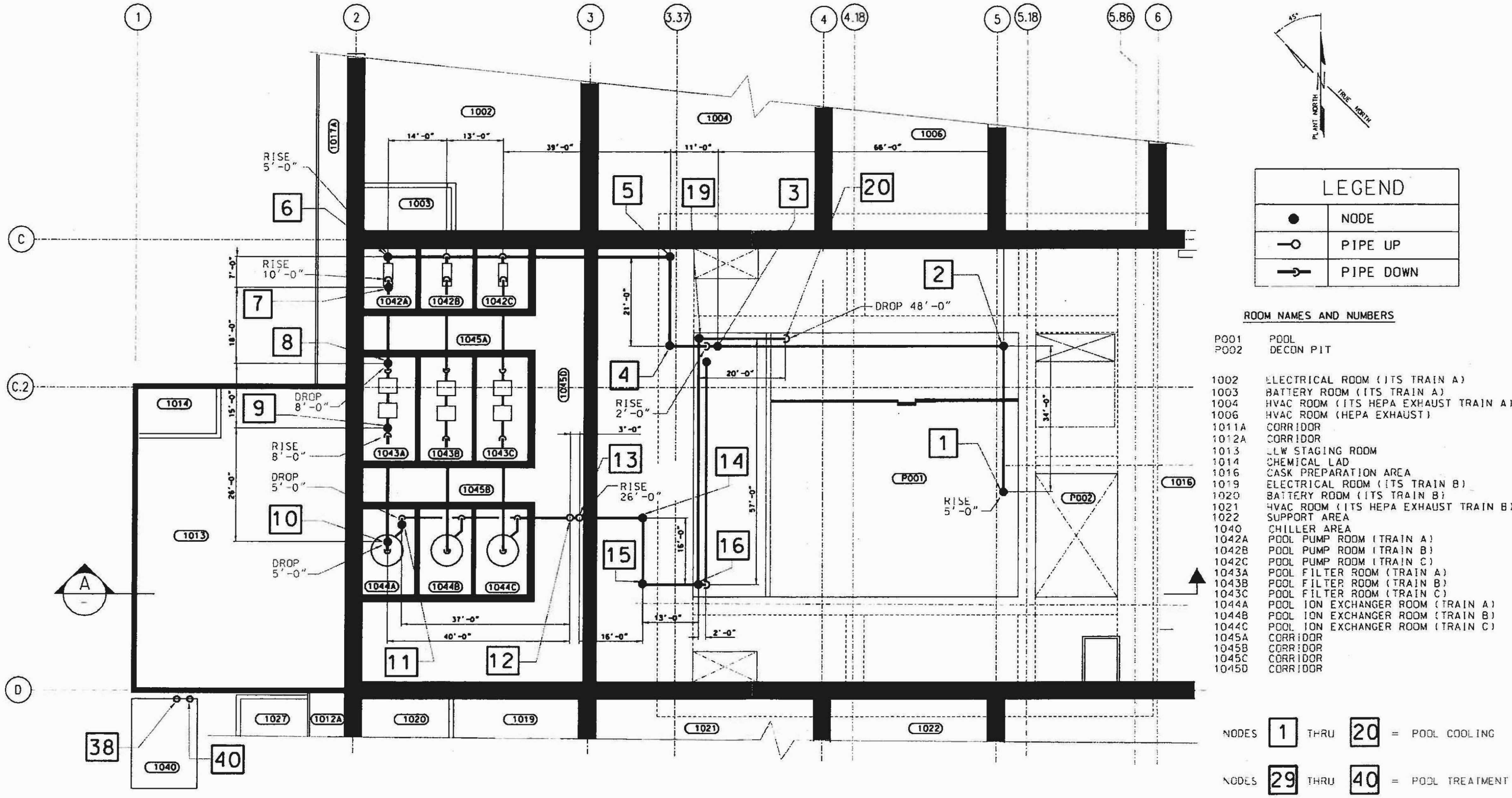
- The $NPSH_A$ for the sump pumps is 29 ft (Section 6.5.3.2).

7.6 POOL CLEANING EQUIPMENT

- Five, 260 gpm underwater vacuum units (050-PW00-SKD-00002A, B, C, D, and E) are used to vacuum particles from the bottom and sides of the pool (Section 6.6). Each underwater vacuum unit will require a 10 hp motor, have a pressure drop of 30 psi, and have a 0.1 micron rating (Section 6.6).

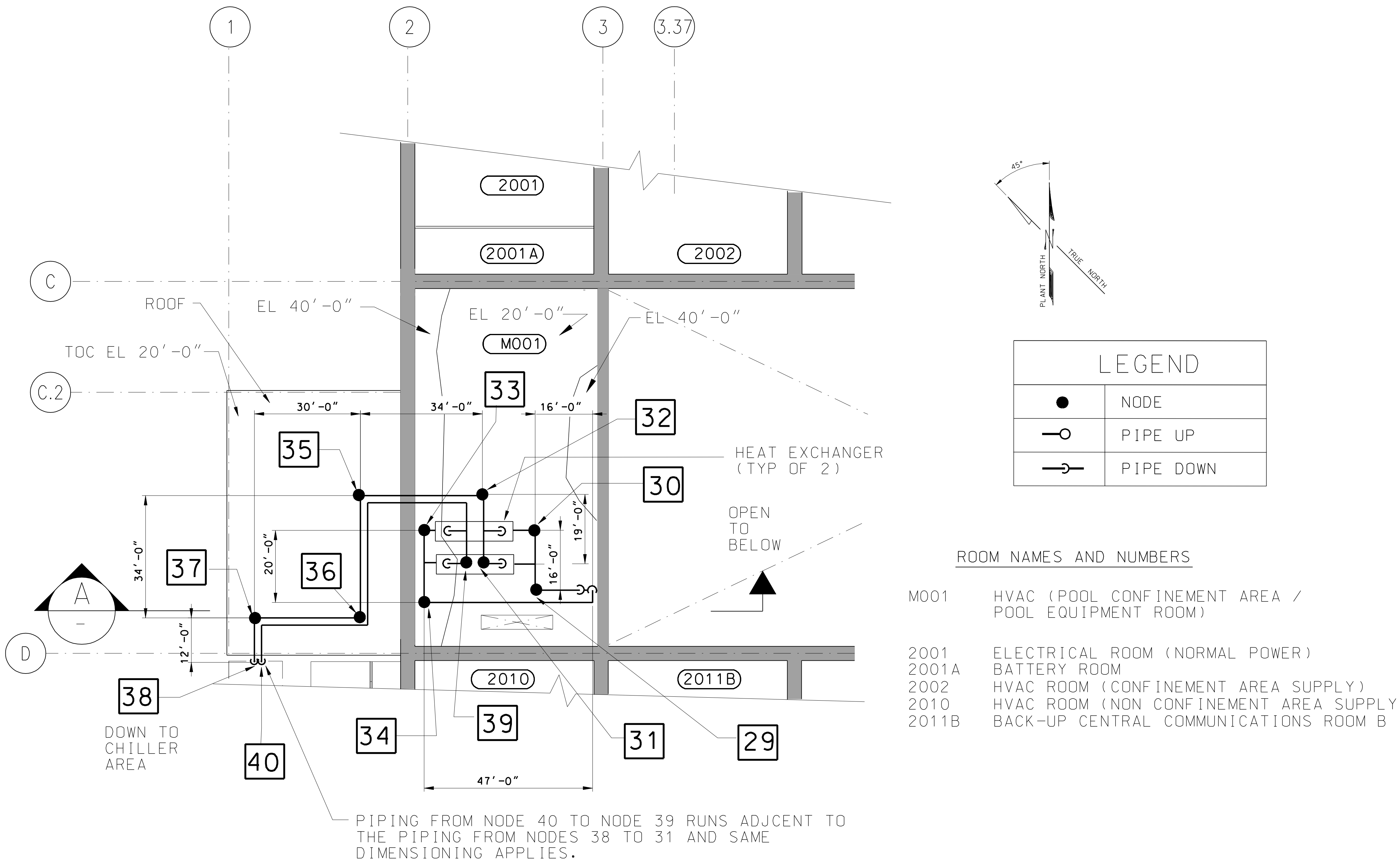
- The floating skimmer (050-PW00-SKR-00001) can be attached to an underwater vacuum unit to filter the surface of the pool for floating debris at a rate of 100 gpm (Section 6.6).

ATTACHMENT 1
POOL WATER TREATMENT AND COOLING SYSTEM PIPING LAYOUT
(Sheet 1 of 3)



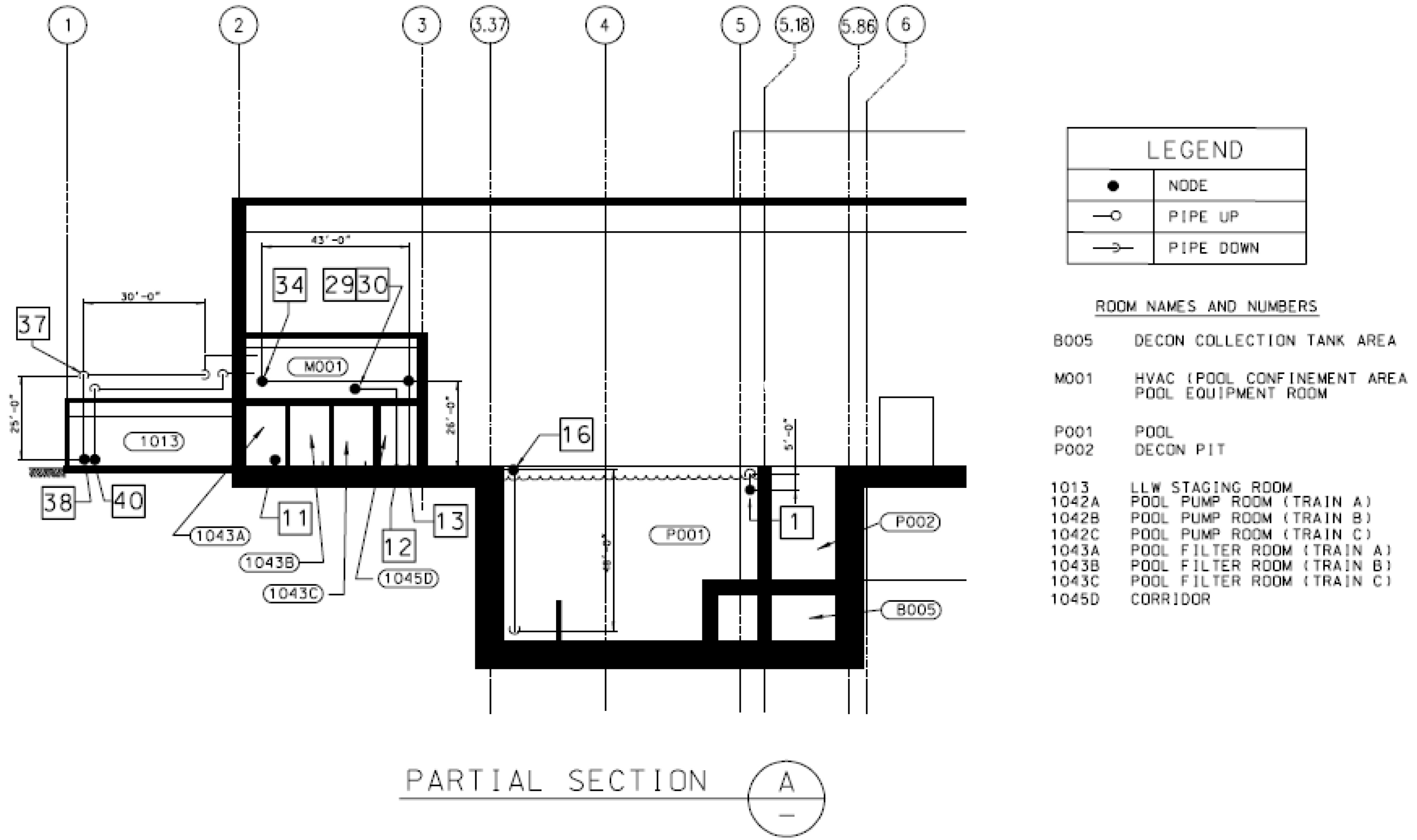
PARTIAL WET HANDLING FACILITY
ENLARGED GROUND FLOOR PLAN AT EL 0'-0"

ATTACHMENT 1
POOL WATER TREATMENT AND COOLING SYSTEM PIPING LAYOUT
(Sheet 2 of 3)



PARTIAL SECOND FLOOR PLAN AT EL 40'-0"

ATTACHMENT 1
POOL WATER TREATMENT AND COOLING SYSTEM PIPING LAYOUT
(Sheet 3 of 3)



ATTACHMENT 2
GILBERT BOISSY E-MAIL REGARDING SPENT FUEL POOL TURNOVER RATE
(Sheet 1 of 1)

Gilbert Boissy on 03/28/2007 02:53:27 PM

To: Jennifer Quigley/YM/RWDOE@CRWMS
cc: Document Control@CRWMS
Subject: Spent Fuel Pool Turnover Rate

LSN: Not Relevant - Not Privileged
User Filed as: Excl/AdminMgmt-14-4/QA:N/A

Jenna,

I have worked with spent fuel issues in Commercial Nuclear Plant for many years. Other than re-racking, fuel sipping, or re-constitution , the spent fuel pool in commercial nuclear plants really see no action for 18 months at a time depending on their refueling cycle schedule. Even then clarity can become an issue.

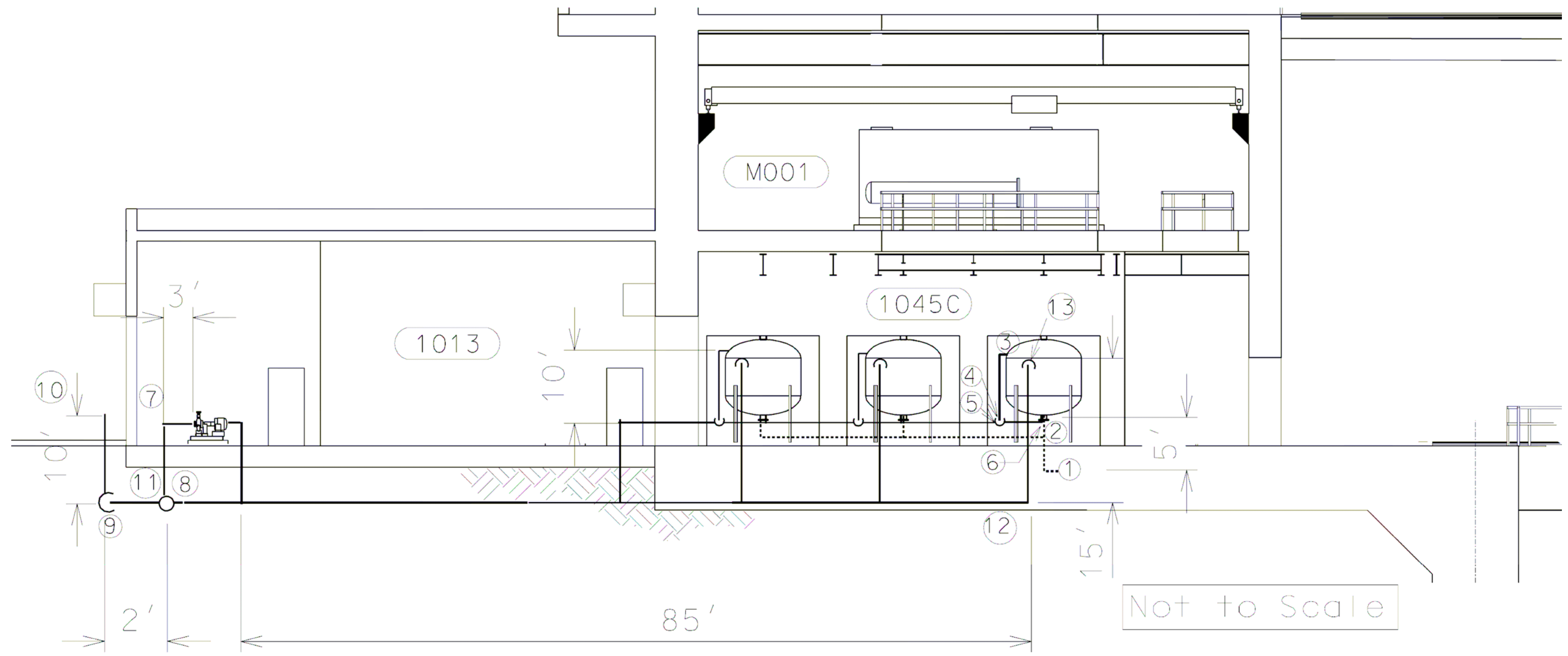
I worked on a Core Barrel Repair Project which worked a 24/7 schedule. Drill Machines and tooling were constantly coming out of the Reactor Cavity Pool and Clarity was an issue along with high radiation levels. We had the normal cooling systems in operation and up to three TriNukes in operation all of the time filter change outs were frequent.

I recently worked on a decommissioning project on a commercial nuclear plant. I was a shift manager responsible for all aspects of fuel transfer from spent fuel pool to canister, vacuum drying, helium inerting, transfer to truck, and transfer to storage pad. We maintained the pool clarity by utilizing extra pool clean up equipment and Trinukes. This job was worked on a 20/7 schedule. This job was completed on schedule and budget. Spent Fuel Pool clarity was a key issue in that without the extra cleanup measures we would have slowed down due to the inability to read the fuel serial numbers.

At the Yucca Mountain Project Operations has reviewed the operating conditions that will probably exist in the WHF spent fuel pool and we have strongly recommended that for a 24/7 fuel processing schedule that a high turnover rate of 24 hours be established.

Gil Boissy
Operations

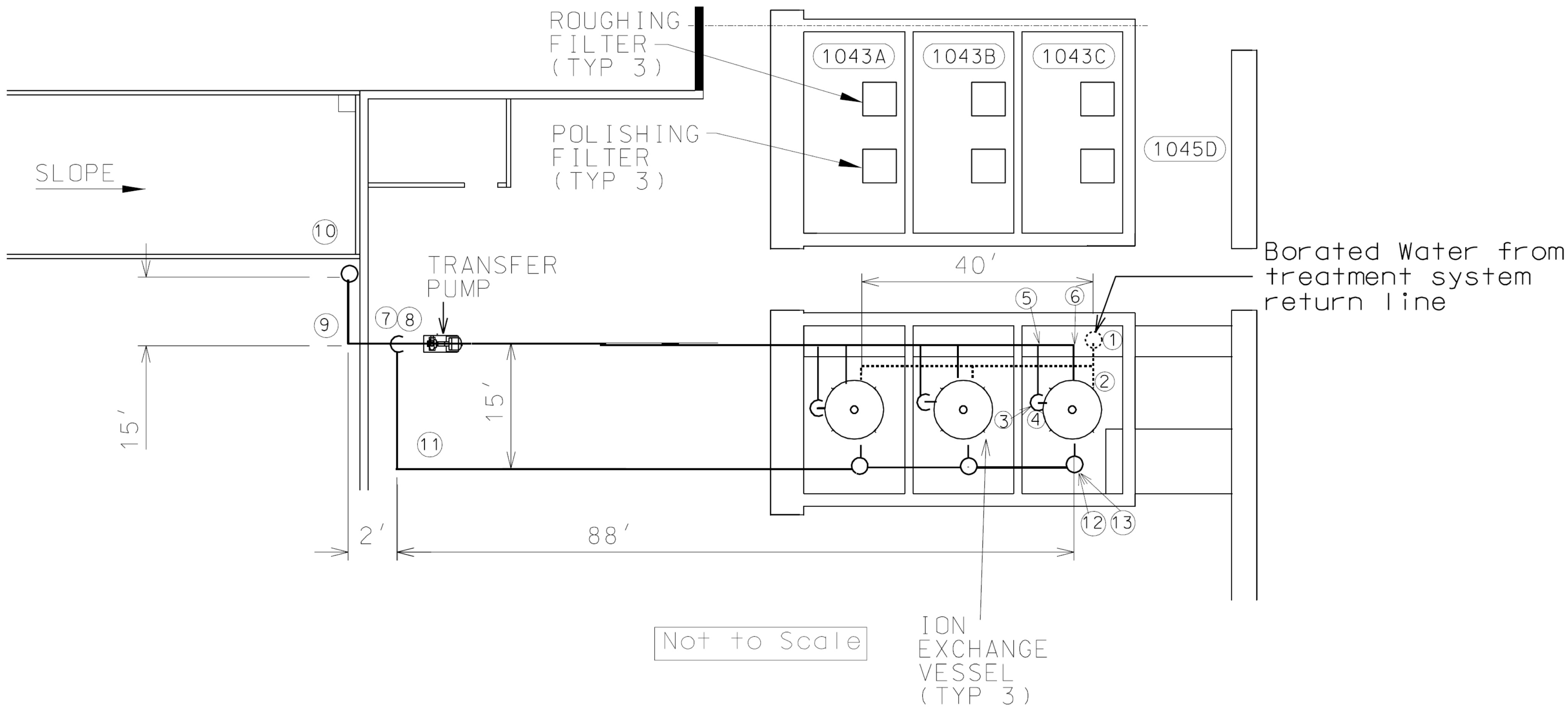
ATTACHMENT 3
SPENT RESIN HANDLING SYSTEM PIPING LAYOUT
(Sheet 1 of 2)



Spent Resin Handling System Pipe Nodes	
Node 1	Connection to treatment system return line (elevation -1 ft)
Node 2	Inlet to ion exchanger (fluidization header)
Node 3	Outlet of ion exchanger (upper sluicing)
Node 4	
Node 5	Connection to main sluicing line
Node 6	Outlet of ion exchanger (lower sluicing) (4 ft)
Node 7	Discharge of transfer pump (centerline elevation 1.5 ft)
Node 8	
Node 9	
Node 10	Connection to slurry receipt vessel (elevation 4 ft)
Node 11	Inlet to recirculation pipe
Node 12	
Node 13	Inlet to ion exchanger (recirculation)

ATTACHMENT 3
SPENT RESIN HANDLING SYSTEM PIPING LAYOUT

(Sheet 2 of 2)



BSC	**Calculation/Analysis Change Notice** *Complete only applicable items.*	1. QA: N/A 2. Page 1 of 1

3. Document Identifier: 050-M0C-PW00-00100-000	4. Rev.: 00C	5. CACN: 001

6. Title:
Pool Water Treatment and Cooling System

7. Reason for Change:
Corrective action for CR 12053.

8. Supersedes Change Notice: ☐ Yes If, Yes, CACN No.: ______ ☒ No

9. Change Impact:

Inputs Changed:	☒ Yes	☐ No	Results Impacted:	☐ Yes	☒ No
Assumptions Changed:	☐ Yes	☒ No	Design Impacted:	☐ Yes	☒ No

10. Description of Change:

- In Section 2.2, page 11, **add** the following:

2.2.44 ASHRAE 2003. *2003 ASHRAE® Handbook, Heating, Ventilating, and Air-Conditioning Applications.* Inch-Pound Edition. Atlanta, Georgia: American Society of Heating, Refrigerating and Air-Conditioning Engineers. ISBN: 1-931862-22-2.

- On page 51, Section 6.4.1, second paragraph, change reference for Equation 12 **from**: (Reference 2.2.28, p. 4.7) **to:** (Reference 2.2.44, p. 4.6)

11. REVIEWS AND APPROVAL

Printed Name	Signature	Date
11a. Originator: Lee Hunsaker		5/15/08
11b. Checker: Eric Slaathaug	Eric Slaathaug	5/15/08
11c. EGS: Maurice LaFountain	NP	5-19-08
11d. DEM: Hang Yang		5-19-2008
11e. Design Authority: for Barbara Rusinko		5/28/2008

BSC

Calluation/Analysis Change Notice

Complete only applicable items.

1. QA: ~~QA~~ N/A LHH 6/30
2. Page 1 of 1

3. Document Identifier: 050-M0C-PW00-00100-000	4. Rev.: 00C	5. CACN: 002
6. Title: Pool Water Treatment and Cooling System		
7. Reason for Change: To provide the electrical power requirement for the air-cooled chillers.		
8. Supersedes Change Notice: ☐ Yes If, Yes, CACN No.: ______ ☒ No		

9. Change Impact:

Inputs Changed:	☒ Yes	☐ No	Results Impacted:	☒ Yes	☐ No
Assumptions Changed:	☒ Yes	☐ No	Design Impacted:	☐ Yes	☒ No

10. Description of Change:

To the end of Section 2.2, page 11, **add the following:**

"2.2.45 Carrier 2004. *AQUASNAP®, 30RB060-390, Air-Cooled Chillers*. Syracuse, New York: Carrier. TIC: 257949."

"2.2.46 McQuay International 2007. *Air-Cooled Scroll Compressor Chiller (AGZ 030CH - AGZ 180CH, Packaged Chiller / AGZ 030CB - AGZ 180CB, Chiller with Remote Evaporator; 30 to 180 tons; 60 Hertz, R-410A)*. Minneapolis, Minnesota: McQuay International. TIC: 260133."

To the end of Section 3.1, page 22, **add the following:**

"**3.1.31 Cooling Water Chiller Power Requirement**

Assume the power requirement for the air-cooled chillers is 110kW.

Rationale – The power requirement for the air-cooled chillers is based upon the cooling capacity and the maximum condenser entering air temperature. Because the chillers are located external to the WHF (Attachment 1), the maximum condenser entering air temperature is equivalent to the maximum ambient air temperature, which is 116°F (Reference 2.2.11, Section 6.1.6). Based on vendor data, the power requirement of a 64 ton chiller (Section 6.3.6) with a condenser entering air temperature of 115°F and a leaving water temperature of 50°F (Assumption 3.1.13) is between 104.3 kW (Reference 2.2.45, p. 42, through interpolation) and 105.1 kW (Reference 2.2.46, p. 22, through interpolation). Conservatively, 110 kW will be used. The difference between the condenser entering air temperature of the vendor data (115°F) and the maximum ambient air temperature of the site (116°F) is negligible."

To Section 7.3, page 65, **add the following** as the ninth (9th) bullet**:**

"• The air-cooled chillers have a power requirement of 110 kW each (Assumption 3.1.31)."

11. REVIEWS AND APPROVAL

Printed Name	Signature	Date
11a. Originator: Lee Hunsaker	[signature]	6/27/08
11b. Checker: Eric Slaathaug	Eric Slaathaug	6/27/08
11c. EGS: Maurice LaFountain	NY [signature]	6-27-08
11d. DEM: Hang Yang	[signature]	6-30-2008
11e. Design Authority: ~~Barbara Rusinko~~ B 30JUN08	[signature]	30 JUNE 2008